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DEPARTMENT OF THE ARMY FIELD MANUAL

**LOGISTICS
SELECTIVE MANAGEMENT
OF
SECONDARY ITEMS**



**HEADQUARTERS, DEPARTMENT OF THE ARMY
DECEMBER 1965**

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HEADQUARTERS
DEPARTMENT OF THE ARMY
WASHINGTON, D.C., 9 December 1965

LOGISTICS

SELECTIVE MANAGEMENT OF SECONDARY ITEMS

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PART ONE

INTRODUCTION

CHAPTER 1

GENERAL

Section I. PURPOSE AND SCOPE

1. Purpose

a. This manual sets forth Army doctrine pertaining to the selective management of secondary items. It is designed to furnish guidance for operating agencies in the field and to provide a teaching basis for appropriate courses of instruction in the Army school system. It describes, explains and expands on the theories, principles, and techniques related to inventory management and the supply control of secondary items. Further, it provides an introduction to the concepts and mathematics of scientific inventory control systems and techniques to facilitate a closer understanding of the reasons underlying present procedures while stimulating a questioning and innovating attitude on the part of inventory managers and item analysts. The material presented herein is applicable without modification to both nuclear and nonnuclear warfare except as otherwise noted.

b. Users of this manual are encouraged to submit recommended changes or comments to improve the manual. Comments should be keyed to the specific page, paragraph and line of the text in which the change is recommended. Reasons will be provided for each comment to insure understanding and complete evaluation. Comments should be forwarded direct to the Commandant, U.S. Army Logistics Management Center (USALMC), ATTN: AMXMC-L-D, Fort Lee, Va. Source data cut-off date for material contained in this publication in June 1965.

2. Scope

a. This manual is directed to the application of selective inventory management techniques for the management of military secondary item inventories by item managers, primarily at the National Inventory Control Point (NICP) and Oversea Inventory Control Point (OICP) level of the wholesale logistics system. Middle and top managers of the Army's supply management system are encouraged to apply the principles and concepts outlined in this manual.

b. The subject is developed in two parts—

(1) *Part One—Introduction.* Treated here are the purpose of logistics, the problems facing logisticians, management concepts, and the organizational elements most concerned with secondary item management.

(2) *Part Two—Supply Management.*

(a) A description and an analysis of present techniques and procedures used by the NICP's to manage selectively secondary items is presented here. Coverage includes—

1. Selective Management;
2. Collection and Analysis of Data;
3. Forecasting Techniques;
4. Stratification of Inventories;
5. Cost Considerations;
6. Supply Control Studies and Systems;
7. Repairables; and
8. Standards, Performance and Evaluation.

- (b) Briefly described are the important cost/performance optimizing systems currently in use or under development within the Department of Defense (DOD), the use of research simulation models and Automatic Data Processing (ADP) considerations. In addition, a basic presentation of scientific inventory control techniques is provided extensively using examples and

graphics to facilitate understanding. These include—

1. Statistical Distributions and Curve Fittings;
2. The Economic Order Quantity (EOQ);
3. Variable Safety Levels (VSL);
4. Reorder Points (REOPT);
5. Inventory Models; and
6. Demand Forecasting.

Section II. APPLICATION AND OBJECTIVE

3. Application

This manual applies to items stocked based on repetitive demand and is for use by item managers at National Inventory Control Points and by inventory managers worldwide.

4. Objective

The primary objective of this manual is to provide information on which to base actions to attain more effective and economical levels of supply through the utilization of economic

order and procurement policies, and to establish and maintain optimum operating levels and variable safety levels to provide necessary protection against out-of-stock positions by the application of statistical and mathematical principles. Selective management is not limited and should be exploited to the maximum extent. Every possible management improvement and modern inventory technique should be used to insure support of the Army in the field at a minimum cost through their vigorous application at all materiel management echelons.

CHAPTER 2

COMPLEXITY OF LOGISTICS

Section I. GENERAL

5. The Challenge

a. The primary purpose of logistics is the provision of needed supplies and services to support combat operations. As the nature of warfare changes, logistics—if it is to be successful—must adapt itself to these changes. During periods when means and methods of combat are relatively stable, moderate adjustment in logistics concepts may suffice. But when revolutionary advances are occurring in combat capabilities and techniques, as is presently the case, it behooves military planners to intensify their analysis of the probable pattern of warfare and make certain that logistics is keeping pace. It is not enough that improvements in logistics methodology be limited to those which are prompted by weaponry alone. Logistics managers must be alert to *any* new product, concept, or technique developed by industry or the government itself which can be used to improve the effectiveness or economy of Army logistics. During an era of explosive technology an Army that stands still is predestined to defeat. The nation which does the best job of applying advanced developments in these fields within its military establishment *now* will have a distinct advantage should armed conflict be inevitable.

b. The Army's logistics system, then,—if it is to fulfill its support role effectively—must be continually modernized in order to reflect the dynamic changes being wrought in the tactics, techniques and tools of nuclear-age warfare. The pace of evolution is swift; “trial and error” methods are hopelessly slow, uncertain, and expensive when applied to the derivation of advanced logistics technology. Operations research is a valid means of assuring the scientific deduction and preinstallation

testing of new logistics concepts. Today, ever-increasing emphasis must be placed on the speed and efficiency of supply operations, particularly in the area of accurate and rapid requirements computations. Increasing automation now permits fast and sophisticated manipulation and analysis of huge masses of data. Decision making is becoming ever more demanding and a premium is placed upon trained logistics managers who can quickly separate vital facts from minutiae and make accurate decisions on the basis of logical deduction.

c. Predictions within the Army are influenced by such intangibles as long standing and ever-changing national policy implications of the international political environment, national budgetary policies, balance of payment deficits, steady advancement in military technology and current research and combat developments activity. Also, because of the remoteness of prospective combat areas, the U.S. Army may be forced to expose longer, more vulnerable lines of communications than those of potential enemies. National morality prevents the United States from initiating a war. Consequently, the advantages of being able to develop a wartime logistics system based on a known time and place of commencement of hostilities is lost. What is actually necessary is an optimum wartime logistics system in being at all times. However, powerful pressures for economy prevail in peacetime and, as a result, the Army must accept a logistics system which represents a compromise between what it needs and what it can afford. These overriding considerations place emphasis on both effectiveness and cost of supply. Inefficiencies and inaccuracies are of great concern

to the Army because its supply requirements represent such a large portion of the nation's total resources. It is the task of supply managers to appraise and control the cost of supplying needed materiel on time and in required quantities without impairing the ability to supply. This is indeed a difficult task necessitating a high order of management competence.

6. The Response

a. The Army works ceaselessly to increase its combat capability to meet the ever-changing challenge of aggressor nations. In this endeavor it strives for qualitative superiority in communications, firepower, mobility, and materiel support in depth rather than attempting to match potential enemy forces man for man. Fast, efficient means of communications are being developed to provide dependable information on a timely basis. Emphasis is being placed on air transportability of weapons, equipment and backup support to bolster combat effectiveness. In the procurement area, the Army has stretched out its objectives to prevent block obsolescence of weapons and equipment. It is using its assets fully by aiming at a goal of peak efficiency at the lowest possible cost. Through the use of measured modernization it is promoting an orderly flow of new items into the inventory, maintaining a stable production base and eliminating uneconomical surge buying.

b. The Army materiel readiness posture is affected by changes in requirements, modernization, and the status of the inventory of Army assets. The Army staff has made a complete review of materiel development, procurement, and allocation procedures and, as a result, by adjusting the qualitative and quantitative requirements for equipment to closely calculated needs for current operations and mobilization reserves, it has been able to reduce requirements or delay procurement for many items making possible the procurement of other essential items. The use of multiyear contracts has stabilized production of complex items of equipment with their attendant high start-up costs, and has provided industry with the advantages of a stabilized labor force and the Army with a base for continuous production of the items under contract. To speed the

decision-making process on higher levels and to reinforce control of funds and programs, improved management techniques have been adopted and put into effect. Automatic data processing programs are being used to bring under control the mass of logistics data the Army accumulates in its varied and far-flung activities. Scientific management tools and new and streamlined reporting systems are steadily improving the Army's management of its resources. Supply management is experimenting with inventory models of the symbolic, deterministic, and stochastic types which afford mathematically oriented logisticians with representations of operations or systems under study and permit them to manipulate the mathematical model and arrive at an optimum solution to an inventory problem without disturbing the real world. Supply managers are constantly seeking to develop a more flexible and balanced system capable of providing readily whatever degree and kind of support might be required by national policies. Methods of accounting for reimbursable transactions are being simplified and modernized. The use of revolving stock and industrial funds continue to contribute to more efficient management. The problems of anticipating all the contingencies that might arise are enormous and involve many intangibles; however, the Army has and is making strides to cope with them selectively and rapidly.

c. There is no single area in the military science where error is so readily discernable as that portion concerned with the determination of materiel requirements. Although much has been written about the magnitude and diversity of the Army inventory and the attendant difficulty of managing the thousands of items stocked, inventory managers have not as yet found a means of either attaining or sustaining an optimum inventory position on a routine basis. While much is being done to achieve this goal, the herculean task of managing an inventory for a vast spectrum of end items ranging from small arms to complex missile systems and their accompanying repair parts presents a great number of problems as yet unsolved. Further, the situation is compounded by the heterogeneity of equipment, the variety of makes and models, the types of programs involved, the diversified geographical

deployment and the multi-missions of the users. Some of the problems of inventory management stem directly from its size; others arise from the wide range of items stocked; many items are low in cost and are easily obtained through commercial channels; still others are expensive, complex and essential to the Army's mission and can be acquired only through close coordination between the Army and industry; some are issued in large volume on a recurring basis and demand for them is relatively easy to forecast; others have never been issued and demand for them is difficult to predict. In addition, Army inventories are characterized by rapid and unpredictable change in makeup due to the accelerated pace of inventory modernization.

7. Management Concepts

a. In view of the size, variety and changing nature of the Army inventory it is apparent that it can be managed effectively only if the task is broken down into manageable segments. The basic philosophy in approaching this task is generally one of management by exception and selectivity of management time and effort based upon the importance and dollar value of items. The inventory is broken out into segments—

- (1) By Commodity Organization—the commodity commands of the U.S. Army Materiel Command (USAMC) are essentially commodity organizations charged with management of items peculiar to their respective missions.
- (2) By Commodity Management—within the USAMC commodity commands there are commodity management centers—National Inventory Control Points (NICPs)—at which the worldwide management of inventories of assigned commodities is carried out. The individual commodity manager at the NICP is responsible for the management of specific items within the commodities assigned to him. This responsibility includes catalog direction, requirements computation, budgeting, procurement direction, distribution management, overhaul

direction, and excess determination. As a result, all of the wholesale functions of inventory management are centralized in one individual at one place.

- (3) By Stratification—this in effect is a division of the inventory into categories which are distinguished by the type of funds used to procure the items, their importance in the inventory and the manner in which requirements are computed. These categories are—

Category	Funds
(a) Principal Items ----	PEMA (Procurement of Equipment and Missiles, Army)
(b) Secondary Items ----	PEMA/OMA (Operation and Maintenance, Army)/Stock Fund
(c) Repair Parts ----	PEMA/Stock Fund

- (4) Project Management—while not a specific segmentation process by itself, project management is a specialized method of handling particular weapon (support) systems by a single project manager and provides for various techniques of planning, controlling, progress reporting and decision making. It is a means of reducing materiel leadtime and establishes a basis which allows for a single authority to plan, direct and control a weapon or equipment system. It includes all phases of research, development, procurement, production, distribution, and logistics support to maintain a balanced program for the acquisition of operational systems and equipment on time, meeting requirements and characteristics, at reasonable costs.

b. Because of strategic, economic and inventory management necessity and similarity of characteristics, the categories mentioned above are further grouped into two broad areas: principal items and secondary items (including repair parts). This segregation is a valid and desirable management technique to differentiate between the methodologies applicable to

the procurement, supply control and distribution policies inherent in them. For many years the Army has traditionally segmented its inventory for management and financial reasons. These categorizations represent two entirely divergent management systems.

- (1) The first grouping, principal items, can generally be identified as—
 - (a) Having a high monetary value;
 - (b) Having an unduly short or excessive inventory position;
 - (c) Being difficult to procure or produce;
 - (d) Being essential for combat or training; or
 - (e) Requiring critical materials for their production.

- (2) The second grouping, secondary items, can be identified as generally having the opposite criteria, i.e., short leadtime, low value, ease of procurements, etc. Principal items are included in authorization documents (Tables of Distribution and Allowances (TDA) Tables of Organization and Equipment (TOE)) which serve as the basis for requirements computation and issue.

c. The second grouping, secondary items, can be identified as being computed on the basis of forecasted demand. Some are exceedingly high cost, critical items requiring comprehensive management attention while others are low cost, have a short leadtime, are easier to procure and need less management emphasis.

Section II. PROBLEMS CONFRONTING INVENTORY MANAGERS

8. General

a. Although the Army has developed logical and workable solutions to the intricacies of inventory management, and the priorities established for equipping and sustaining its combat and support forces are basically sound, there are still a number of problem areas which make it difficult—if not at times almost impossible—to accomplish the task with optimum efficiency and accuracy. For example—

- (1) The impact of nuclear weapons on the logistician and in turn on the inventory manager is especially difficult to visualize. The use of atomic weapons may reduce the use of conventional ammunition. But to determine just how much reduction and in what types, has an impact on the item analyst. The overall effect of this is quite important as ammunition, both conventional and nuclear, represents a sizeable portion of the Army's budget. Further, nuclear weapons and the threat of nuclear war has an effect on tactics and organizations, and the resulting requirement to support these changes is hard to evaluate, particularly when the inventory manager must project his requirements into

the future—in some cases, a matter of years. Nuclear developments have made themselves felt in other areas. The development of all types of equipment has been compressed in time with the result that the problem of satisfying a requirement with an item of equipment that will not become obsolete in the immediate future presents the inventory manager with the task of modernizing his inventory to keep pace.

- (2) Modernization is one of the most perplexing problems facing the Army today. To maintain an acceptable readiness position during the current cold war environment and in the face of rapid technological change with its attendant high rate of obsolescence, and to do it with limited funds, poses the question of how much to buy for war reserves and just what items. The ability of the inventory manager to answer these questions has a considerable bearing on the Army's readiness position.
- (3) Reduction of items in the inventory commensurate with adequate support to troops is essential. It can be ex-

pected that the type of warfare which will be conducted in the future will not permit supply of the wide variety of items stocked in peacetime, and which have been made available in past wars. Several programs are at work reducing the number of items in the inventory. Through the Defense Standardization Program, responsibility for reducing the various items of supply and maintaining the reductions has been assigned to the military departments and the Defense Supply Agency (DSA) in terms of complete Federal Supply Classification (FSC). The Defense Utilization Program, administered by DSA, provides for the optimum utilization of assets through the transfer of releasable assets between the military services and the reutilization of excess materiel to meet new requirements and thereby reduces expenditures for new procurement. Another is the Federal Catalog System which provides a common identification language, eliminates different identifications of like items, reveals interchangeability among items, aids in standardization, facilitates inter- and intra-departmental support, assists industrial mobilization and strengthens government-industry relationships. Not only the Army, but all logistic agencies, in keeping with the policies of the Department of Defense, are maintaining constant vigilance in assuring that all items of supply, or authorized for supply, are items for which a real need exists, eliminating to the greatest possible degree, those which fall into the nice-to-have category.

- (4) Reduction of repair parts is a function of maintenance policy and practice. Extensive repair at forward echelons results in a higher requirement for a broader range of items than a policy of replacement of major components only.

b. The accumulation of asset data, the application of replacement factors and the analysis of demand are interrelated in that to properly perform these tasks the commodity manager must receive accurate reports from the field concerning quantities of items on hand and in use equipment densities.

- (1) Since assets on hand are applied to a gross requirement to determine the net quantity required it is essential that asset data be accurate and timely. The fact is, however, that accurate data is difficult to obtain. When consideration is given to the number of makes and models and diversity of items involved, together with their worldwide distribution, the problem is better appreciated.
- (2) Replacement factors are those applied to "in use" quantities of items to provide for anticipated losses over a specified period of time. Since it is difficult to determine exactly how many of a given item is in the supply system, it is even more difficult to obtain information as to what happens to each and every item. An exact picture of when and why an item leaves the system, whether it has been consumed or worn out or merely un-serviceable but reparable is needed for the computation of replacement factors. Further, new items of equipment, on which there is no issue or demand experience, are constantly entering the inventory. The replacement factor, in this case, must consider the newness of the equipment as well as the fact that it is being utilized under conditions employing new tactical concepts. In these cases replacement factors must be based on engineering estimates or on experience generated on equipment having similar characteristics and adjusted as usage experience becomes available.
- (3) Demand analysis is, as it implies, an analysis of demands placed on the inventory manager at the NICP. The analysis is made to determine the relationship between recurring demands

and nonrecurring demands as identified by the requisitioner at local levels and the worldwide demands which are expected to be repetitive at the NICP level. Demands must be screened to identify the one-time initial issue, the project or program demand and the abnormal requisitions. These must be analyzed as to whether they represent unusual demands caused by a particular event or circumstance expected not to recur, are covered by furnished program requirements or are a true normal demand which can be projected as future requirements. The effect of nonavailability of consumer funds on demand history must also be analyzed. In addition, seasonal demand, cyclic demand, age of equipment, etc., must be taken into consideration in the analysis process since future requirements are normally computed based on at least a two year demand history.

c. Many of the inventory manager's problems actually stem from limitations on funds and resources. It is recognized that unlimited funding and resources are not practicable possibilities. This, however, must be faced. These represent overriding constraints which force inventory managers to provide the greatest accuracy and the most efficient management in the determination of requirements to adequately support the Army's overall materiel requirement at minimum cost. When funds are short, managers may have to delay procurement on some items in order to use available funds to purchase more urgent needs.

9. Magnitude of the Inventory

a. There are few management responsibilities in the world today which parallel, in scope and complexity, that of managing the Army's inventory. Some of these problems arise from its size and diversity; others are due solely to the many echelons through which an extended supply pipeline must reach out to support the combat forces located in all parts of the world.

b. Of foremost concern is the size and value of the inventory itself; if it is larger than necessary to meet current and anticipated

needs, the cost of maintaining the system is substantially increased. Excessive inventory also raises costs associated with obsolescence and eventual disposal. As the costs of managing the Army supply system vary with the size of the inventory, continued emphasis is placed on the assessment of supply performance in terms of—

- (1) What is being done.
- (2) How efficiently it is being done.

10. Diversity of Items

a. The management of a multi-billion dollar inventory is a monumental undertaking. The task becomes even more complex when items within the inventory range from those—

- (1) Which are low cost and easily obtainable to high cost, difficult to procure items with exceptionally long lead-times;
- (2) With readily identifiable demand and distribution patterns to those which are difficult to forecast because of erratic demand and eccentric distribution; or
- (3) Specialized items of equipment which are distributed on a geographical basis due to a multiplicity of makes and models, to the modern tank distributed to specific units and organizations in identifiable numbers based on authorization documents.

b. Further, support of these end items with components, assemblies, subassemblies and repair parts present an even more formidable problem to the inventory manager.

11. Modernization

Technological change is a constant and desirable factor but poses the problems of what items to procure, how many, and how long they should be retained in the supply system. Throughout history, the conduct of war has changed from period to period and weapons and their supporting systems have become more complex and effective. In the past generation, technological developments have proceeded at a geometric rate and the military arsenal of nuclear weapons and missiles bears little resemblance to that of 30 years ago. The change, moreover, has been reflected in more

than basic weapons. Supporting equipment and even clothing and food have undergone a similar degree of change. Improvements in weapons and their employment have always been a necessary adjunct to military responsibility, however, the introduction of new weapons and equipment poses complex problems for current inventory managers and particularly difficult ones with respect to the accumulation of mobilization reserve stocks over certain periods of time. As time passes, expanding technology renders these reserves obsolete and the military system is correspondingly weakened. Within these constraints, secondary item support demands constant attention by inventory managers to insure purging the system of nice-to-have items while maintaining an acceptable and attainable readiness posture.

12. Clear Lines of Authority and Responsibility

One of the purposes of the Army Reorganization in 1962 was to provide a materiel or-

ganization responsive to national emergency. This was achieved with the establishment of USAMC featuring authoritative control over all Army wholesale materiel operations and charging the command with the clear responsibility for delivering suitable equipment and supplies in required quantities to Continental United States (CONUS) installations and oversea commands. Concurrently the Deputy Chief of Staff for Logistics (DCSLOG) was relieved of his command-like responsibilities and his planning and policy responsibilities were reemphasized. Under the current concepts and organizational structure policy direction flows from the Secretary of Defense through the Assistant Secretary of Defense (Installations and Logistics) (ASD I&L), the Assistant Secretary of the Army (Installations and Logistics) (ASA I&L), the DCSLOG to the USAMC where it is placed into operation.

Section III. THE NATIONAL INVENTORY CONTROL POINT (NICP)

13. Integrated Materiel Inventory Management

a. NICP's (fig. 1) are organizational segments within a commodity command which have been delegated responsibility for the integrated materiel inventory management of a group of items. Within the NICP, individual commodity managers are assigned a given number of items by category, such as all items required for support of a given end item, or Federal supply classification groups or classes within a category for integrated inventory management. This also consists of the management of related logistics missions, subject to the policies, programs, and control actions over principal items directed by higher authority. Commodity management includes—

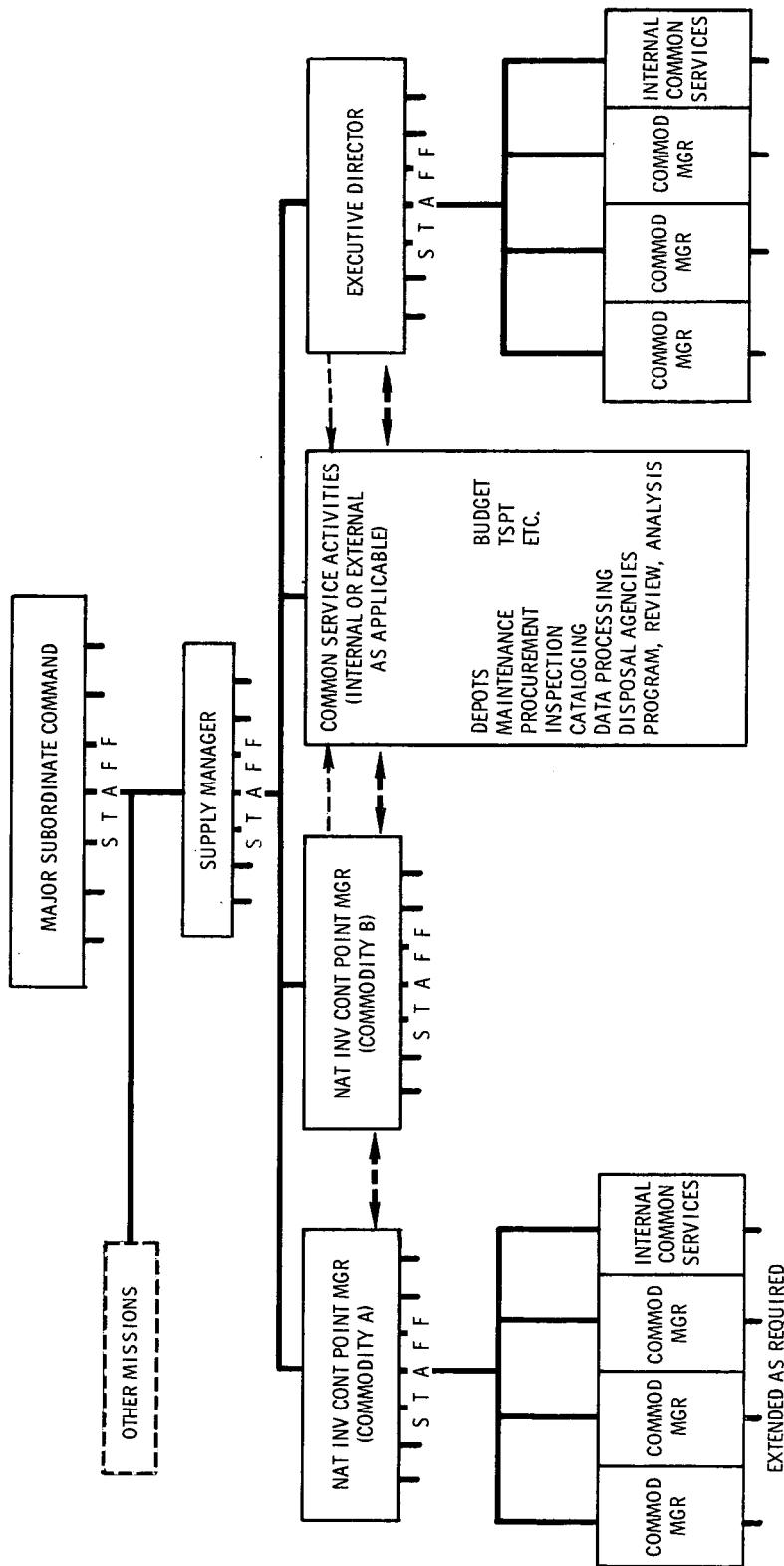
- (1) Cataloging direction—initiation of actions requiring the timely identification of items and preparation of manuals leading to cataloging of items;
- (2) Requirements computation — computation of quantitative requirements;
- (3) Budgeting — preparation of the PEMA and stock fund budgets to pre-

sent requirements for obligation authority;

- (4) Procurement direction — authority, within limits of approved programs, to require procurement to be accomplished;
- (5) Distribution management—control of stocks in, due into or planned for, the distribution system on a quantitative or monetary basis;
- (6) Overhaul direction—authority to require overhaul to be accomplished; and
- (7) Disposal direction—authority to require disposal to be accomplished.

b. The responsibilities of the commodity manager outlined in *a* above recognize the fact that there are many other functions of materiel inventory management furnished as a common service that normally are not a part of his integrated responsibilities. Such common services consist of depot maintenance, procurement, inspection, cataloging, data processing, disposal, programing, review and analysis, transportation, and related activities. These are nor-

THE NATIONAL INVENTORY CONTROL POINT



PROC, REBUILD, CATALOGING DIRECTION,
DISTRIBUTION MANAGEMENT
LIAISON

FOR GUIDANCE ONLY TO ILLUSTRATE SOME OF THE BASIC ORGANIZATIONAL PRINCIPLES INVOLVED IN A COMMODITY TYPE STRUCTURE. DOES NOT PRESCRIBE JOB TITLES OR ORGANIZATIONAL STRUCTURE. THE NUMBER AND MAGNITUDE OF THE SEPARATE NICP'S WILL LARGELY DICTATE THE NEED FOR INTEGRATION WITHIN NICP'S OR THE PROVISION OF EXTERNAL COMMON SERVICE ELEMENTS.

Figure 1. The National Inventory Control Point (NICP).

THE ARMY MATERIEL COMMAND

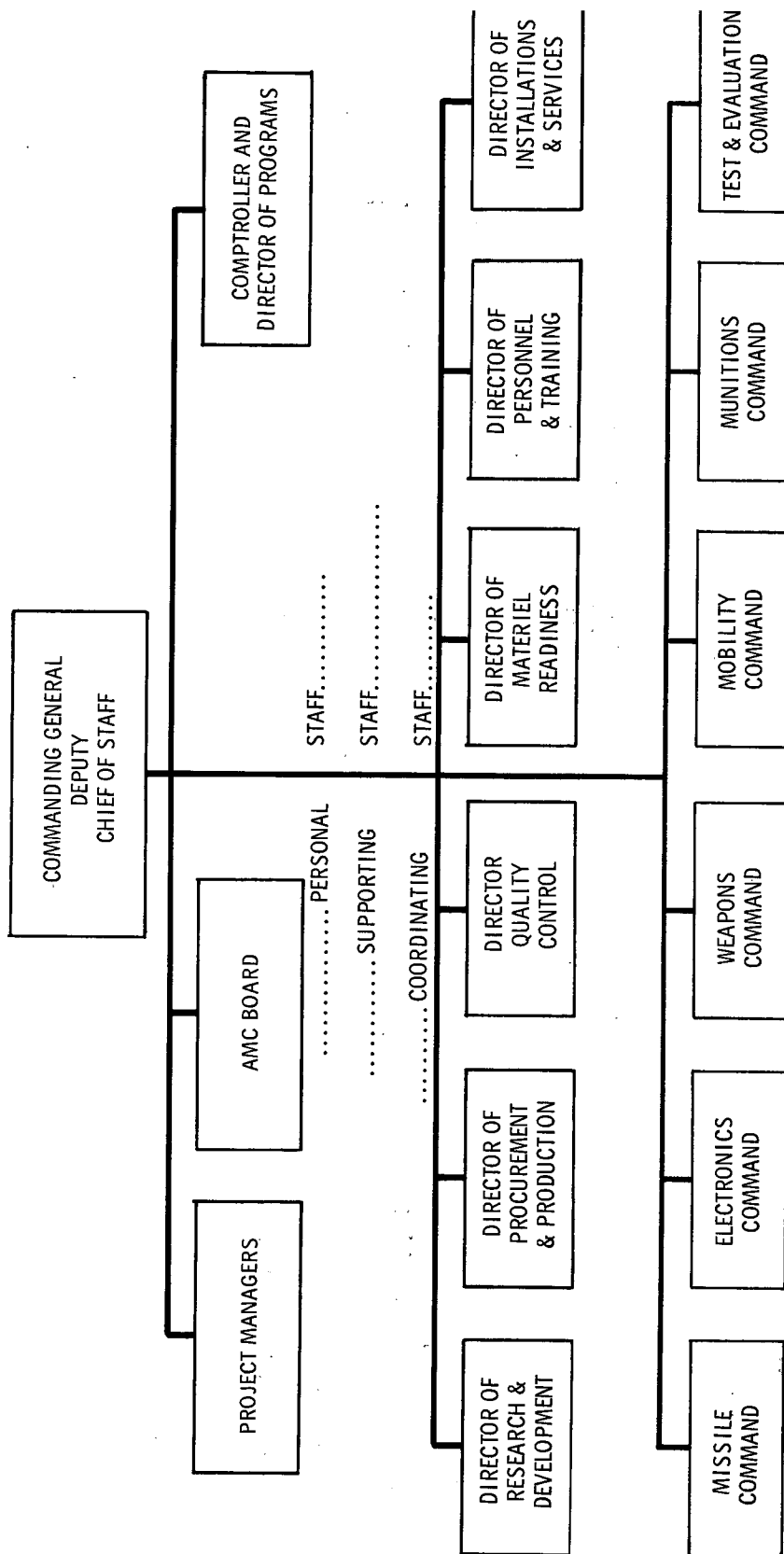


Figure 2. The U.S. Army Materiel Command.

mally furnished to the commodity manager by USAMC, DSA, or an appropriate oversea commander.

c. USAMC (fig. 2) is responsible for the execution of the Army supply mission and implementation of policies, programs, and prescribed control actions established by the Department of the Army (DA). USAMC exercises primary staff responsibility for integrated materiel inventory management for secondary items and for—

- (1) Developing and managing the DA initial repair parts provisioning program.
- (2) Developing and managing (within thresholds specified by DA) the DA worldwide depot overhaul program.
- (3) Worldwide technical advice and assistance through supply and maintenance liaison activities and maintenance technical assistance (AR 750-22).
- (4) Developing implementing procedures for operation of the DA worldwide supply and maintenance system and criteria for measuring of the system.
- (5) The AMC Division of the Army Stock Fund.
- (6) Receipt, storage, issue, control, maintenance, demilitarization and disposal within the CONUS wholesale supply and maintenance system.
- (7) Transportation (to include traffic management) as it relates to the CONUS wholesale supply and maintenance system.

d. Oversea commanders and commanders of other Army agencies are made responsible for the implementation of procedures to accomplish the objectives of integrated materiel inventory management within the scope of their assigned missions.

14. Centralization by Commodity

a. The interrelated functions of inventory management include the determination of types and quantities of items to be brought into the system, obtaining them, controlling them, and eliminating them when necessary. These tasks can best be performed only when the inventory manager has accurate working information. As mentioned above, the NICP is the organization

which the Army has established to coordinate this information.

b. Under the Army's "centralization-by-commodity" concept, requisitions flow directly from the oversea commands and CONUS customers to the NICP handling the commodity desired. Materiel release orders are forwarded electronically by the NICP to the appropriate storage depot which then ships the requisitioned materiel to the customer and notifies the NICP of the action taken.

c. Currently, there are two exceptions to this direct customer—inventory manager relationship.

(1) *Military Assistance Program (MAP)*. Because Military Assistance Advisory Groups (MAAG's) that assist in the initiation of MAP requisitions are usually small elements that may not be capable of maintaining the extensive supply catalog library required to verify requests and because of funding considerations, MAP requisitions flow through and are processed by the Mutual Security Directorate (MSD) in New Cumberland, Pa. This element receives, processes and funds all MAP requisitions and forwards them to the appropriate NICP for supply action.

(2) *Oversea Commands*. In the U.S. Army Europe (USAREUR), the U.S. Army Pacific (USARPAC), the U.S. Army Alaska (USARAL), and the U.S. Army Southern Command (USARSO), theater commanders have established Inventory Control Points (ICP's to process requisitions before forwarding them to the appropriate CONUS NICP.

d. The commodity manager at the CONUS NICP must receive the information needed as a basis for sound supply decisions. This includes stock status information, detailed analyses of depot issues and receipts, repair and rebuild schedules, demand analyses, procurement status, reports of stocks with troops, as appropriate, and stock fund and financial inventory reports. In addition, liaison visits to depots, installations, and oversea areas provide additional first-hand information to the NICP and the individual commodity manager.

Section IV. THE RELATIONSHIP OF SECONDARY ITEMS TO PRINCIPAL ITEMS

15. Principal Items

a. Principal items are selected for analysis and examination at the DA general staff or AMC level of all factors affecting their supply and demand. Decisions concerning them are normally made at departmental or higher levels and review is extremely detailed. They receive management scrutiny at every stage of the process. This is necessary for both strategic and economic reasons, recognizing that the supply status of these items, to a great extent, governs the supply levels of a large portion of the secondary items in the supply system. In some groups of principal items, such as vehicles, the dollar value of a few may exceed the total value of hundreds of thousands of repair parts, accessories and assemblies needed for their support. Such items are individually identified in use and in reserve and are issued only upon specific authorization, or for special projects. Inventory levels, in the sense of bulk stock measured in "days of supply" or some other pipeline factor, are not significant for these items.

b. From the point of view of supply management, as well as strategic necessity, the segregation of principal items from secondary items is a valid and desirable management technique as procurement, supply control, and distribution problems are basically different for these various categories of supply. Dollar inventory turnover figures might be severely distorted by the inclusion of items of all categories in the same reporting group.

c. Major supply problems in this area involve the establishment of allowances based on troop strength and missions to determine the total initial allowance plus provision for any known future requirement; the addition of sufficient quantities to replace those items of the initial materiel which are expected to be worn out through fair wear and tear and expected losses under combat conditions; computation of stock necessary to initially fill the pipeline to include levels of stock in the oversea depot system and quantities in transit between the CONUS and oversea areas; the attainment of all materiel necessary to support

operational projects; and the application of assets from overhaul or rebuild operations. Accurate budgeting, phased expenditures of procurement funds, identification of assets, long-range programming and anticipation of changes in program elements are all necessary to insure continual improvement and modernization of major weapon or support systems.

d. The basic elements considered in the management of principal items are initial allowances, replacement issues, on hand or in-transit items and those issued for operational projects. The sum of the factors considered gives the total Army requirement as of the date of the study based on troop strength. Demands for agencies other than the Army are stated separately based on guidance stated in the Materiel Program. Information as to current assets is collected semiannually on a worldwide basis determining stocks in hands of troops, at stations, at depots and in-transit. This data is collected through the Army Supply Status Reporting System (AR 711-5). Because assets are accounted for down to and including those in the hands of troops worldwide, the method of management is known as the "Worldwide Gross Method." In addition to the four basic elements mentioned, two additional sources are considered—receipts from procurement; and anticipated receipts from overhaul or repair.

e. Forecasts of principal items constitutes an important element in the computation of requirements for allied secondary items. Because a single major item may require hundreds or even more repair parts or accessories the supply of these items depends to a great extent upon the planned future use and geographical distribution of the end item itself (fig. 3).

16. Secondary Items

a. Although principal items are precisely defined and specific criteria are established for their selection, the same is not true for secondary items. These are currently defined as "end items, replacement assemblies, parts and consumables, other than principal items."

ELEMENTS OF REQUIREMENTS COMPUTATION

FOR

PRINCIPAL ITEMS

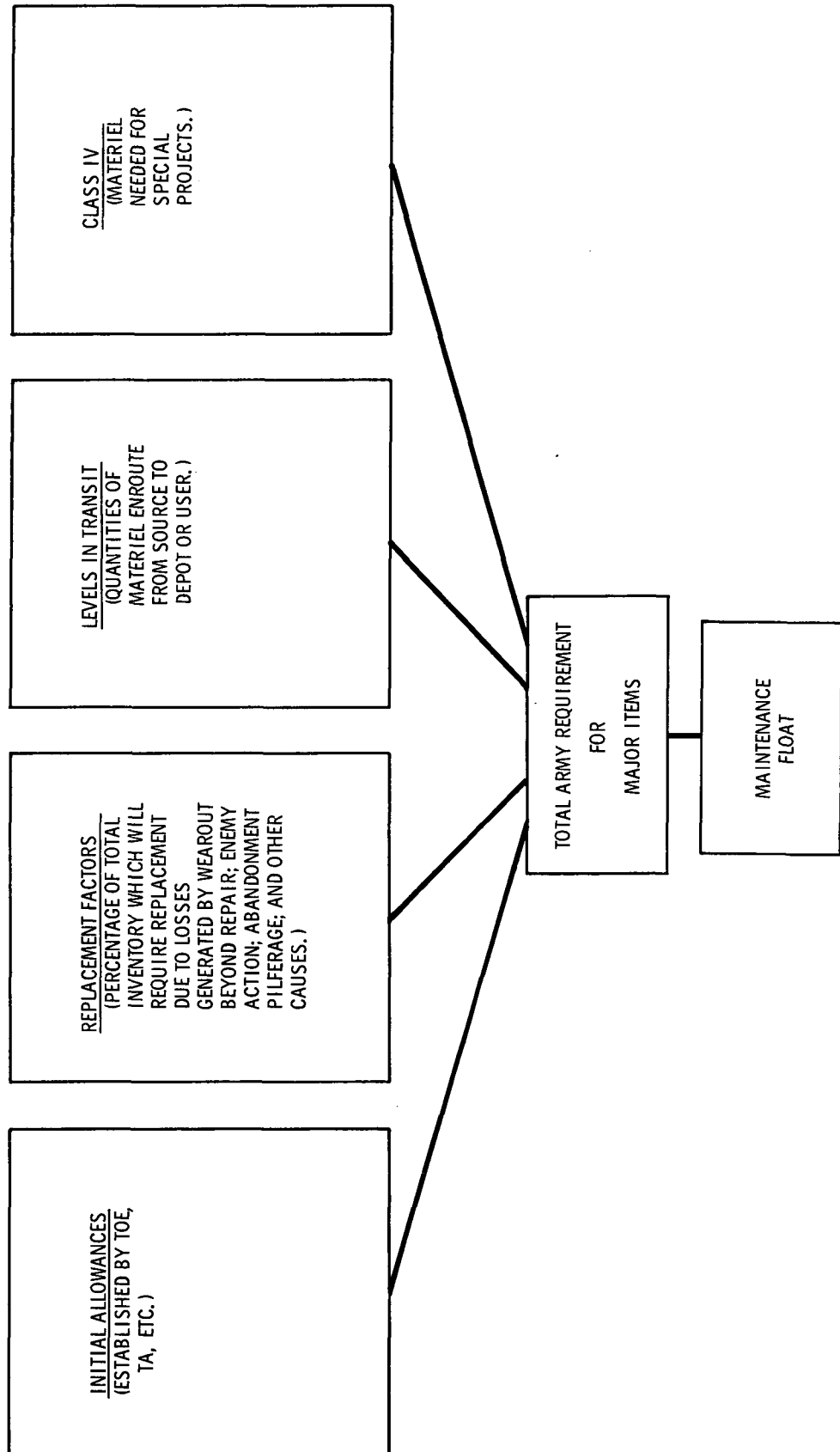


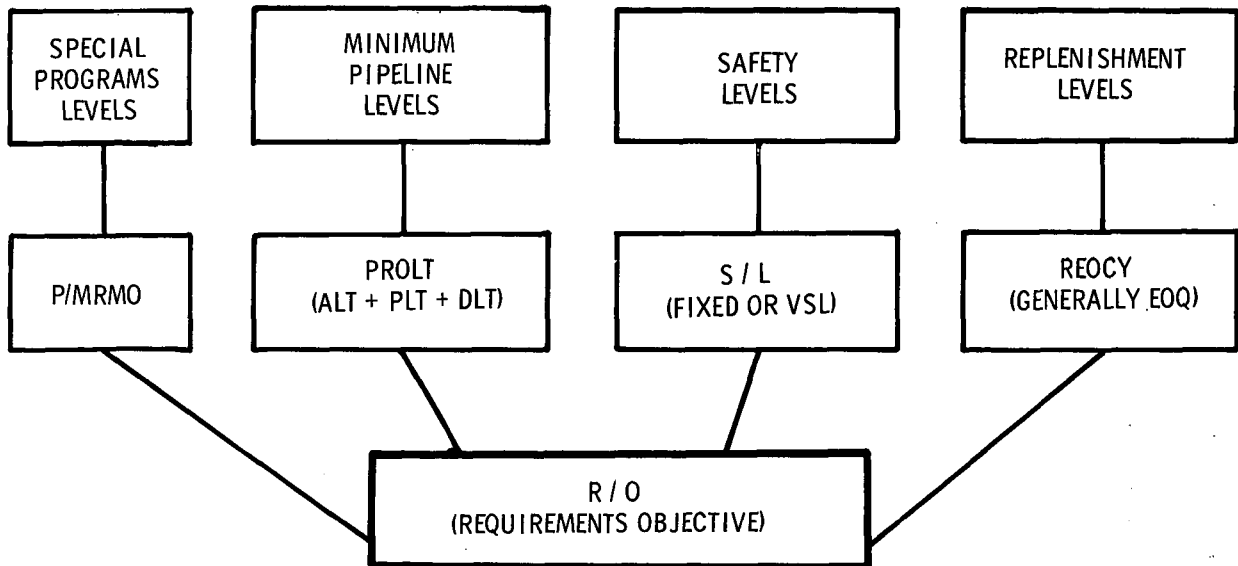
Figure 3. Elements of requirements computation for principal items.

ELEMENTS OF REQUIREMENTS COMPUTATION

FOR

SECONDARY ITEMS

(MATERIEL PIPELINE REQUIREMENTS)
(WHOLESALE)



$$(R/O = P/MRMO + PROLT + S/L + REOCY)$$

$$** \text{ REOPT} = P/MRMO + PROLT + S/L \text{ (=WHEN TO BUY)}$$

$$**** \text{ REOCY} = (\text{GENERALLY EOQ}) \text{ (= HOW MUCH TO BUY)}$$

** WHENEVER AN APPRECIABLE DELAY EXISTS BETWEEN THE CUT-OFF DATE OF STOCK STATUS REPORTS AND THE DATE OF THE SUPPLY CONTROL STUDY, REOPT WILL BE ADJUSTED TO REFLECT THE LAG TIME, i.e.,
 $\text{REOPT} = P/MRMO + PROLT + S/L (+ SSLT).$

**** AT WHOLESALE LEVEL, REOCY QUANTITY MAY DIFFER FROM THE OPERATING LEVEL. SINCE AT WHOLESALE LEVEL, REOCY IS GENERALLY THE EOQ, DELIVERIES OF TOTAL BUY MAY BE PHASED -- THUS OPERATING LEVEL WILL BE ONLY A PORTION OF THE REOCY QUANTITY.

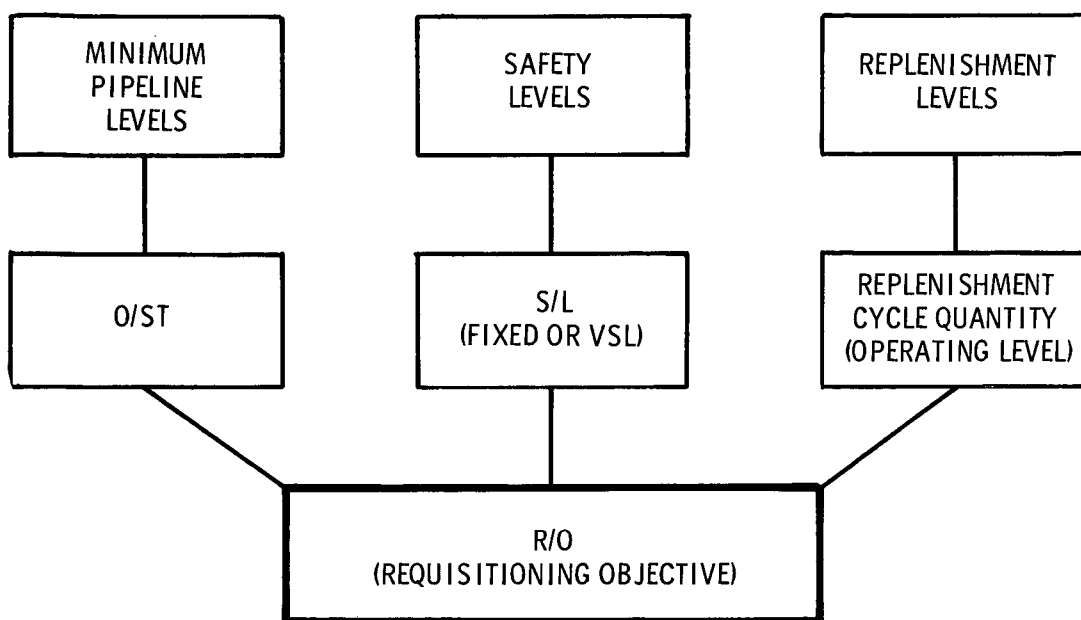
Figure 4. Elements of requirements computation for secondary items (materiel pipeline requirements—wholesale).

ELEMENTS OF REQUIREMENTS COMPUTATION

FOR

SECONDARY ITEMS

(MATERIEL PIPELINE REQUIREMENTS)
(RETAIL)



$$(R/O = O/ST + S/L + \text{REPL CYCLE})$$

$$** \text{ REOPT} = O/ST + S/L (= \text{WHEN TO REORDER})$$

$$\text{REPL CYCLE QTY} (= \text{HOW MUCH TO REORDER})$$

$$S/O \text{ (STOCKAGE OBJECTIVE)} = O/L + S/L$$

** AT CERTAIN SELECTED INSTALLATIONS OR DEPOTS, APPROVED PROGRAMS TO SUPPORT SPECIFIED COMBAT-TYPE UNITS MAY REQUIRE THAT ADDITIONAL LEVELS BE MAINTAINED OH. IN THESE ISOLATED INSTANCES THE REOPT WILL BE ADJUSTED ACCORDINGLY TO INCLUDE RESERVES, i. e.,
 $\text{REOPT} = (\text{RES}) + O/ST + S/L$ (EXAMPLE: ARSTRIKE)

Figure 5. Elements of requirements computation for secondary items (materiel pipeline requirements—retail).

b. Principal items account for a very small fraction of all items stocked in the supply system and for the great majority of the annual procurement and inventory dollars of the Army. The remaining 95 to 98 percent of the items, including secondary items and consumable supplies ranging from antifreeze to zinc have an annual turnover in millions of dollars and require maintenance of inventories on the same scale. Many items in this category have an annual turnover of \$25,000 or more and some selected secondary items are just as critical to military effectiveness and materiel readiness as are principal items. Secondary items account for the great majority of supply management effort. The NICP's of the Army control the stocks of secondary items under AR 710-45. This regulation categorizes the Army inventory into broad divisions based on importance and the dollar value of next year's expected demand. It stresses the paramount importance of selective management, and requires an increasing degree of management for each of the three categories. These are—

- (1) Low value items (LDV), \$2,500 or less.
- (2) Medium value items (MDV), over \$2,500 but less than \$25,000.
- (3) High dollar value items (HDV), \$25,000 and over.

c. There are three principal aspects of supply control of secondary items which vary according to the significance of the item.

- (1) The supply control system requires extensive item-by-item reporting of present assets and past demand history in order to make projections of future requirements. To limit reporting workload the Army prescribes detailed reporting only for high dollar demand items. This detail includes separation of assets and demand by major geographic theaters and distinction of regular replenishment demands from special one-time requirements.
- (2) Additional data are required to support detailed requirements computations for high dollar demand items. These include item applications, projections of end item population (for repair parts), rebuild programs, dues

out included in program and demand forecasts, and other factors which may affect future demand. For items where such data are available, extensive supply control computations are performed manually or by computer, including calculation of "program factors" affecting future demand, repair schedules, and the worldwide system of "pipeline" requirements. For other items, less information is made available and the computations are greatly simplified.

- (3) Finally, the principle of selective and economic management dictate the frequent procurement of high dollar demand items; on the other hand, the administrative cost of review and procurement are significant and must be weighed in relation to total inventory investment.

d. The measures taken in establishing the Army's supply control system apply mainly to the determination of economic inventory levels and procurement frequencies, and to the regulation of workload in data reporting and computation. The Army recognizes that the principle of selective management must be measured against supply effectiveness. Cost is an important factor, but it is subsidiary to keeping troop units in maximum readiness to perform their assigned missions. The contribution of selective inventory control to supply effectiveness must therefore involve the prediction of demand patterns and the establishment of commensurate safety stocks in the supply system to provide effective supply under variable demand conditions.

The foregoing has been a presentation of forces and organizational elements which interact, influence and guide the process of selective management of secondary items. This materiel is included to stimulate thought about and give appreciation to the magnitude of the task and the ever increasing responsibility for the expanding scope of worldwide management of materiel inventories.

The following discusses initially the desirability of having and using selective control and evaluation systems; the characteristics of military inventories; requirements and assets in a time dimension; the importance of minimizing costs with appropriate consideration of national defense and security; and the conflict between minimum annual operating costs and appropriate

tion constraints. Further, the basic elements of selective inventory management are fully treated, both individually and as they affect each other with major emphasis on their relative importance as a means to communicate the general principles and specifics underlying the selective management concept to inventory managers. Maximum use is made of numerical examples, figures, graphs, and charts, utilizing to the greatest extent possible realistic data representative of

Army secondary item experience to illustrate the concepts and techniques.

The dynamic nature of the inventory field and the vast amount of basic and applied research that is being accomplished require periodic translation of research efforts into usable products in order to provide for improvement in requirements forecasts and the evaluation of quantitative materiel readiness for secondary items necessary to support combat operations.

PART TWO
SUPPLY MANAGEMENT
CHAPTER 3
SELECTIVE MANAGEMENT

Section I. GENERAL

17. A Management Principle

The general technique of selective management is widely accepted and applied today as a key principle of good management. Successful managers concentrate their attention on the most important matters while delegating responsibility for activities of lesser interest to subordinates. Delegated matters are reviewed by the manager on an exception basis only when a problem occurs.

18. Criteria for Emphasis

Application of the principle of selective management depends upon the use of meaningful criteria as to what is or is not important. The manager's emphasis should be directed into those areas where he can anticipate a larger return relative to the effort expended; that is, he should concentrate on activities that in-

volve significant cost or have a major effect on performance.

19. Management Systems

An effective management control system is required if managers are to focus their attention and efforts discriminately. The typical management system has three principal parameters— people, procedures, and information. The degree of control exercised is a function of the number and skills of the people assigned to the task, the thoroughness of the analysis and review dictated by the procedures in use, and the comprehensiveness and accuracy of the information applied. A choice normally exists as to how much of each element (people, analytical technique, information) to apply to a given problem. Effective systems fit the effort to the importance of the task.

Section II. INVENTORY DISTRIBUTION

20. Criteria for Classification

a. A well known approach to practical inventory control is to separate the items carried as inventory into two or more classes for selective management. The question arises, however, as to what basis to use for categorization and then where to make the divisions. In other words, how are items to be segregated as to relative importance?

b. Inventories are maintained to permit the fulfillment of a demand for a particular item

without delay. Perfect service to customers would result only if every item were stocked in sufficient quantity to meet any demand. This solution, however, is impractical from both acquisition and storage viewpoints. Large and highly diversified inventories are expensive to establish and maintain. Common practice, therefore, is to stock significant quantities of items demanded frequently or that demonstrate a large variability in demand rate, and not to stock items that are unimportant or readily procurable. This stockage practice sug-

gests two criteria for division of inventories into control groups—demand rate or variability and operational essentiality.

21. Annual Dollar Demand

a. It is generally true that a small number of the total items carried in stock represent a major portion of the total annual dollar demand. This typical characteristic of inventories is graphically portrayed by the curve in figure 6, which represents items stocked arranged in rank order of dollar usage. In the hypothetical

inventory distribution shown, 7 percent of the items represent 50 percent of the total annual dollar demand, point (A), while 25 percent of the items constitute 85 percent of the total annual dollar demand, point (B). This few-items/many-dollars relationship can be, and is, frequently used for selective management purposes. For instance, in the case illustrated, the inventory could be divided at points (A) and (B) into three groupings, each of which could receive a different level of management attention. The 7 percent of the items constituting half of the total annual dollar activity (those

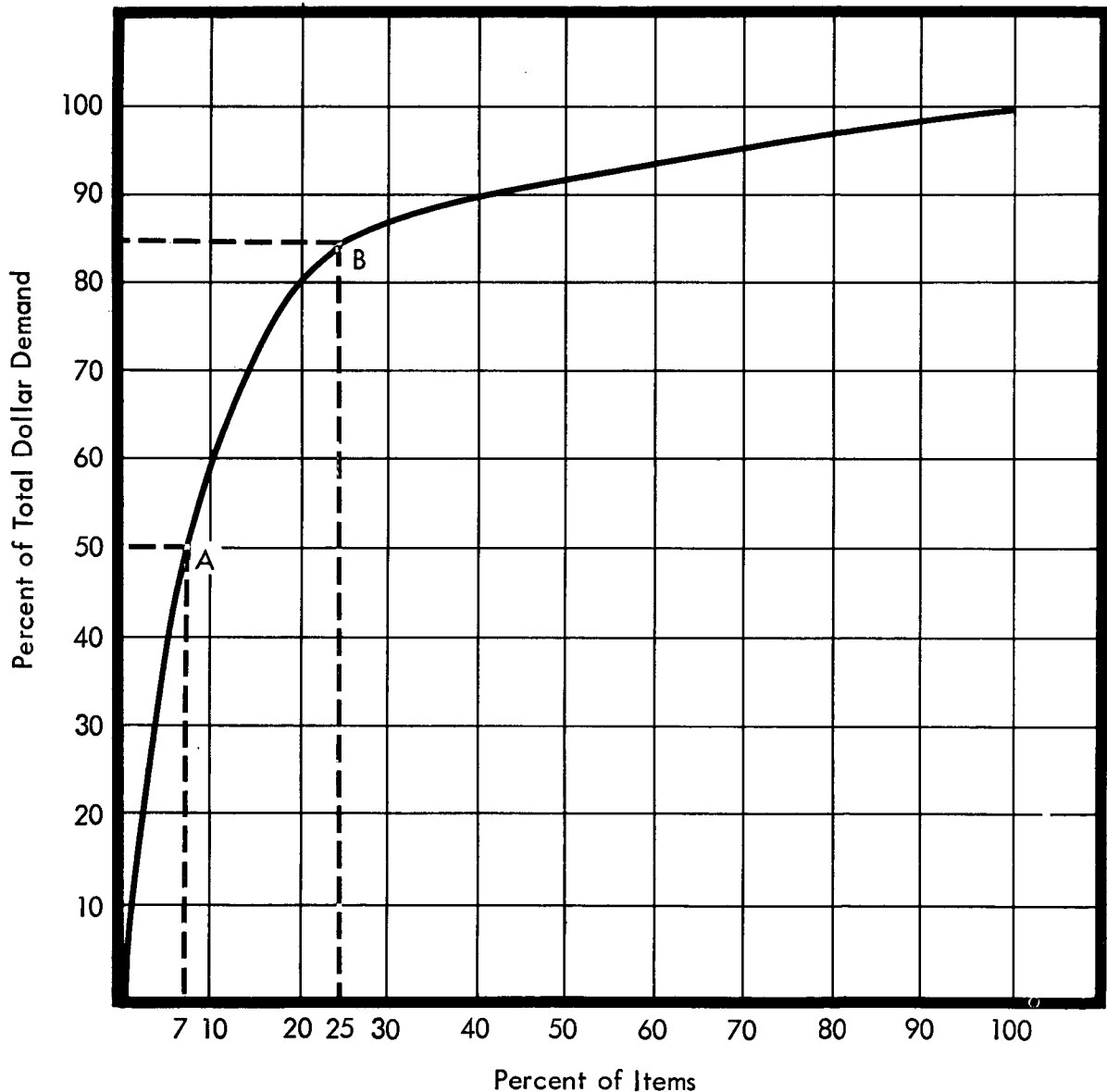


Figure 6. Distribution of an inventory by value.

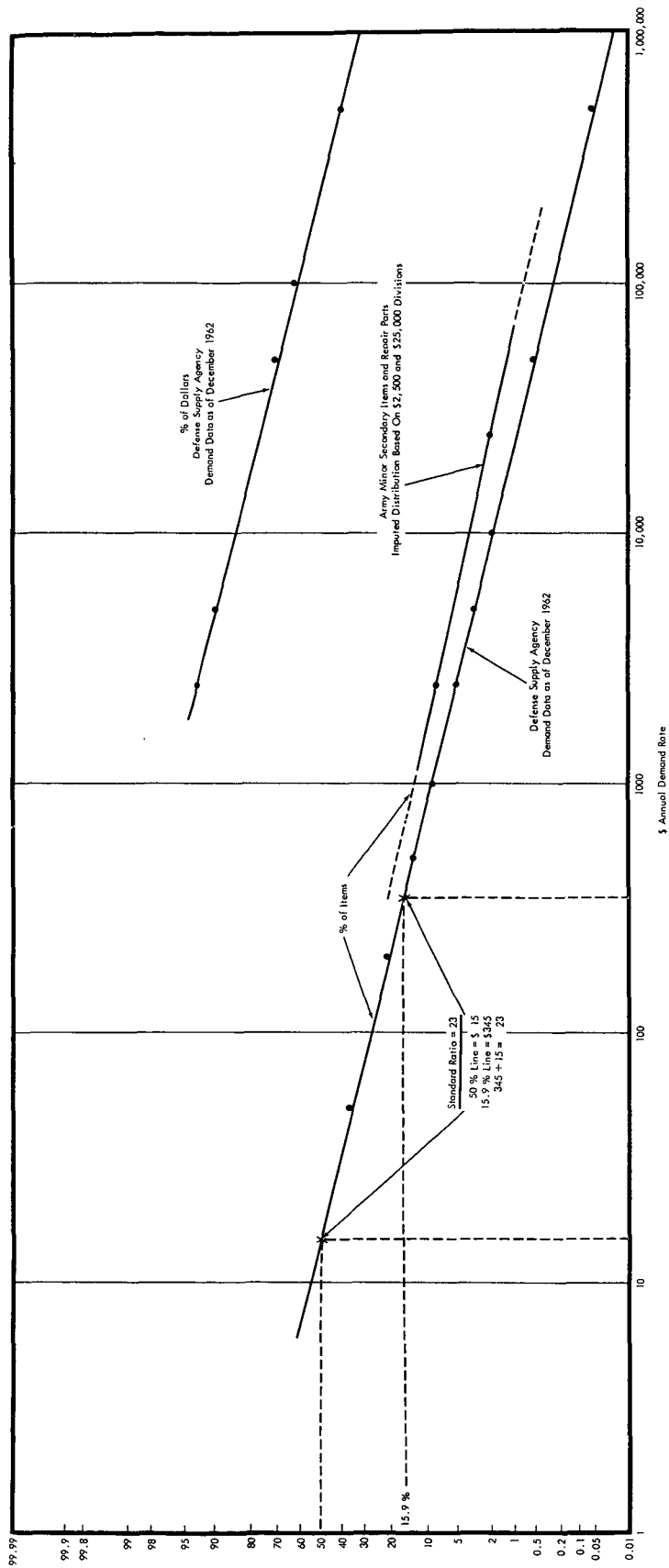


Figure 7. Controlled items distribution plotted on log normal graph paper.

to the left of point A) might be studied frequently, on an individual basis, and in great detail. The 18 percent of the items accounting for 35 percent of the dollar activity between points (A) and (B) might be reviewed less frequently and with less attention to detail. Finally, the low activity items to the right of point (B) (75 percent of items, 15 percent of annual demand) would probably be studied least frequently and then perhaps on the basis of a statistical sample of items rather than on an individual basis.

b. Analyses of many commercial and military inventories have revealed that the vast majority are distributed in a manner that statisticians call a log normal distribution. In a log normal distribution, the logarithm of the variable (annual dollar demand of an item) is normally distributed. The statistical proper-

ties of the log normal distribution are discussed more thoroughly in chapter 16. The term is introduced at this point only to describe accurately the typical form of inventory distributions.

c. While the log normal distribution appears as a sharply rising and leveling-off curve when plotted on linear graph paper (as the curve in figure 6), it becomes a straight line if plotted on log normal graph paper. Figure 7 reveals that log normal paper consists of a normal probability division along the vertical axis while the horizontal axis is divided on a logarithmic scale. The graphed lines represent the approximate distribution of the Army's secondary item inventory and the inventory of the Defense Supply Agency (DSA). A method of developing these graphs as well as the use

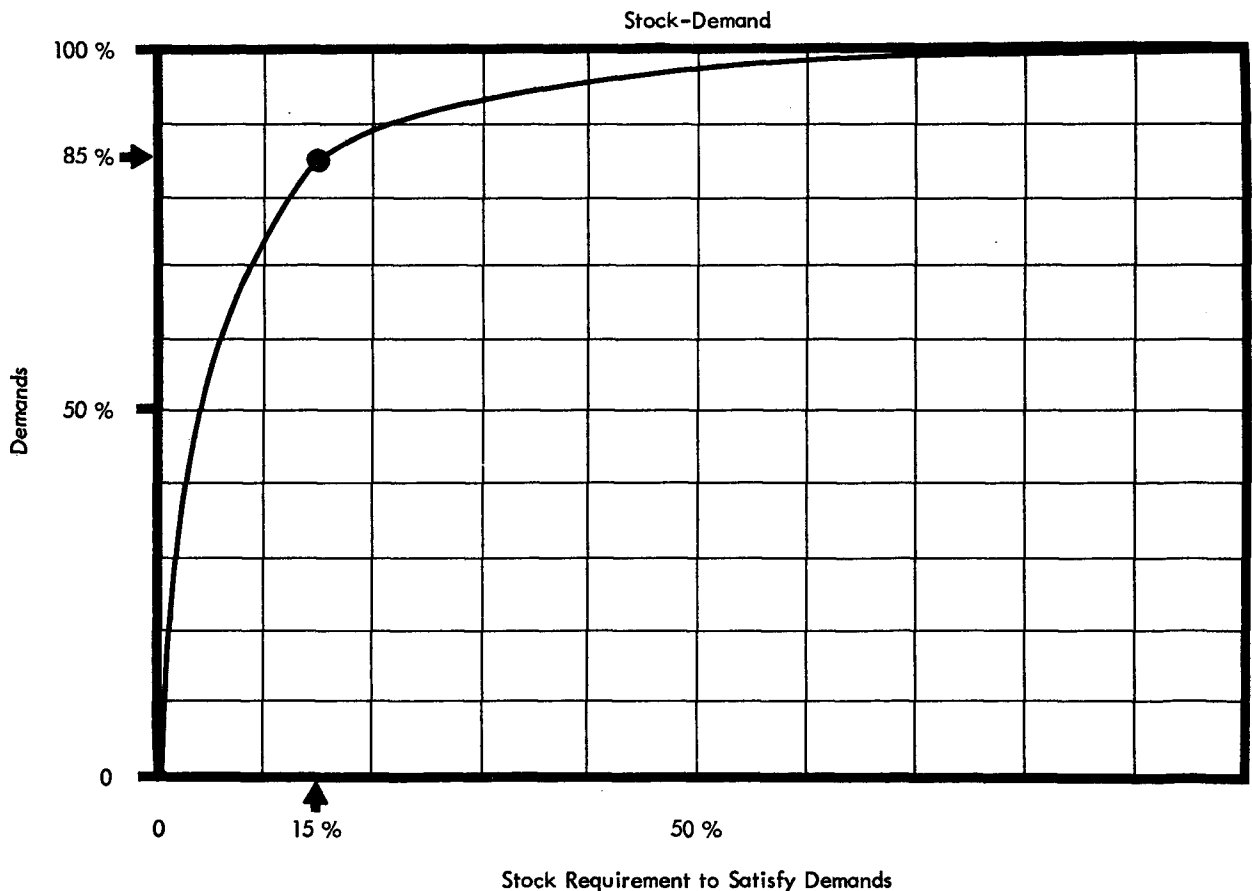


Figure 8. Selective stockage plan.

of the standard ratio are discussed in paragraphs 23 through 26.

d. In addition to the distribution of inventory by dollar demand, the log normal distribution is also characteristic of the distribution of demands for particular items carried in stock. The difference between the two distributions is the variation in unit price of items stocked—a factor that tends to make the dollar demand curve more sharply breaking than the item demand curve. Studies of the item demand relationship, illustrated in figure 8, lead to the development of the selective stockage plan. Selective stockage procedures are founded also, therefore, on the basis of a log normal demand distribution.

22. Selective Stockage Plan

a. AR 711-25 establishes uniform policies and procedures for stockage of secondary items and for the maintenance of authorized stockage lists. These policies and procedures have a decided effect on inventory distributions at all stockage levels and upon the way in which the

Army's multi-echelon system reacts to changes in demand patterns.

b. The key policy here is that stockage is based upon frequency of demand and/or item essentiality. The regulation stipulates the minimum of 3 demands in 360 days as a basis for stockage. The minimum stockage criteria are prescribed by USAMC. However, the stockage criteria must be compatible with the criteria for supported activities.

c. The majority of NICP's interpret the above direction as meaning that they should only stock items that meet the minimum demand criteria unless stockage is justified on the basis of military essentiality. The high log normal distribution standard ratios (20 to 25) that are characteristic of NICP inventories result in part from implementation of selective stockage policies. Were the NICP's to stock all items without regard to demand frequency, standard ratios in the range of 10 to 20 might be observed.

d. The multi-echelon effects of selective stockage policies are discussed in chapter 18.

Section III. CATEGORIZATION OF ARMY INVENTORIES FOR CONTROL PURPOSES

23. Development of Criteria for Division of Inventories

a. An analysis has been made of a representative sample of secondary items to determine where annual dollar demand breakpoints should be made for control purposes. The items in the sample were ranked in columns by annual dollar demand in descending sequence. From this listing, the cumulative item percentages and cumulative demand dollar percentages were calculated. The data were then plotted on log normal graph paper and inspected.

b. Examination of the graph revealed that approximately two percent of the items represented 65 percent of the annual dollar demand with the division occurring at a point of \$25,000 of annual dollar demand. These items were classified as High Dollar Value (HDV) items and were earmarked for intensive management control.

c. Further examination of the data indicated that the vast majority of the items (92 percent) constituted only 15 percent of the annual dollar demand. In this instance, the breakpoint was selected at an annual dollar demand of \$2,500 in order to coincide with the small purchase authority of the Armed Services Procurement Regulations (ASPR). These items were classified as Low Dollar Value (LDV) items, and it was planned that they would receive a minimum of management attention.

d. Items with annual dollar demands greater than \$2,500 and less than \$25,000 were designated as Medium Dollar Value (MDV) items. This classification constituted about 6 percent of the items and 20 percent of the dollars in inventory. They were selected to receive an intermediate level of control emphasis.

24. Item Distribution Analysis by NICP's

a. Secondary items were divided into LDV, MDV, and HDV item classifications to facili-

tate selective management. The divisions of \$2,500 and \$25,000 of annual dollar demand were made somewhat arbitrarily and were based on a relatively small sample of stocked items. Experience may indicate that these division points are not sufficiently selective for each and every NICP. It may be, for example, that a certain NICP would tend to stock a high percentage of HDV items, with very few items falling into the MDV classification. In this case, if the categorization were followed rigidly, the intent of selective management (a very few items controlled stringently, a larger group of items controlled moderately, and the bulk of the items controlled with minimum effort) could not be achieved. For this reason, it is essential that each NICP analyze the dollar demand distribution of the secondary items it controls on a periodic basis at about 2- or 3-year intervals. Whenever a change in classification breakpoints appears desirable, permission to do so should be requests of USAMC. As the characteristics of an inventory are a function of the end items supported, more frequent analysis would not be warranted.

b. As mentioned, the first step in an analysis of inventory distribution is to prepare a list of items ranked by dollars of annual demand. This list may be prepared using Automatic Data Processing (ADP) equipment, a library sort and list routine, and data available on tape memory. It is also desirable to compute and print, for a few selected items, the cumulative items percentages and cumulative dollar sales. These percentages may be easily computed by hand, if a suitable ADP subroutine is unavailable.

c. A rank-order listing of all items carried on an NICP's stockage list can be used as a management tool of sufficient value to justify its cost (in terms of ADP time and expense), if produced at intervals of every 2 to 3 years. However, if the data processing time required for a complete listing cannot be made available, a good estimate of inventory distribution can be obtained through use of random sampling techniques. In this case, a five to ten percent sample (e.g., 5,000 items of a stockage list containing 100,000 items) is randomly selected and listed in rank-order fashion for analysis. When a sampling technique is used,

the representativeness of the sample should be checked by comparing proportional dollar and item totals with those of the total inventory (available from other ADP sources).

d. Whether a total item run or random sample is used, the analyst should have a listing of distribution by demand resembling that shown in figure 9. Here only a few line items are shown to illustrate the ranking technique. In the actual case the list would consist of several thousand items.

e. The next step is to examine the degree of fit with the log normal distribution. This can be accomplished most easily by plotting a selected group of items, representing a wide spread of demand, on log normal graph paper. These points should fall along a straight line.

f. The percentages of items and annual dollar demand can now be compared with those previously used as a basis for item categorization. If less than two percent of the items fall into the HDV classification (over \$25,000 annual dollar demand), some thought should be given to lowering this dividing point so as to give top level emphasis to a greater number of items. Conversely, if more than 10 percent of the items are identified as MDV and HDV items (i.e., more than \$2,500 annual dollar demand), consideration should be given to raising this dividing line so as to delegate the vast majority of the items to a routine and cursory control treatment. It should be understood, however, that an authorization to change dividing lines must be obtained from USAMC.

25. Procedures for Review and Approval of Classification Exceptions

a. The basis for a review by higher headquarters of recommended classification exceptions should be, in part, the log normal distribution analysis outlined above. An explicit statistical measure of how extreme is the few-items/many-dollars relationship is defined as that standard ratio. The standard ratio is the antilogarithm of the standard deviation of annual dollar demands.

b. The standard ratio can be easily determined from the plot of item distribution on log normal graph paper. The standard ratio is obtained by taking the annual demand value

FSN	ITEM COUNT	CUMULATIVE ITEM COUNT PERCENTAGE	ANNUAL DEMAND	UNIT COST	ANNUAL DOLLAR DEMAND	CUMULATIVE DOLLAR DEMAND	CUMULATIVE DOLLAR PERCENTAGE
xxxx-xxx-xxxx (Highest demand)	1	.0005	xxxx	xxxx. xx	x, xxx, xxx. xx	x, xxx, xxx. xx	.5
xxxx-xxx-xxxx	800	1.0	xxxx	xxx. xx	xxx, xxx. xx	xx, xxx, xxx. xx	78.0
xxxx-xxx-xxxx	8,000	10.0	xxxx	xx. xx	xx, xxx. xx	xxx, xxx, xxx. xx	96.0
xxxx-xxx-xxxx	40,000	50.0	xxx	x. xx	x, xxx. xxx	xxx, xxx, xxx. xx	99.9
xxxx-xxx-xxxx (Least demand)	80,000	100.0	0	x. xx	0		100.0

Figure 9. Inventory distribution by annual dollar demand.

where the 15.9 percent horizontal line intersects the fitted line and dividing it by the value of the same line at 50 percent. In figure 7, for example, approximately 50 percent of the DSA items had an annual dollar demand of \$15 or less, while 15.9 percent of the items had a demand of greater than \$345. When 345 is divided by 15, the answer is 23—the standard ratio.

c. Typically, NICP inventories will have a standard ratio in the range of 15 to 30. A ratio of this size means that about 10 percent of the items will constitute 80 to 98 percent of the annual dollar demand. This is to be expected of a high unit value inventory at the wholesale level. On the other hand, in commercial practice, retail soft-goods inventories often have a standard ratio of two to three, in which case the top 10 percent of items might represent only 30 percent of the dollar demand.

d. Any NICP which, upon analysis, has a standard ratio of less than 10 should probably be selectively managing its items on an individually specified classification basis. In this

case, the NICP should recommend a classification revision for consideration by USAMC.

26. Special Classification Considerations

a. Thus far, the only criterion of categorization discussed has been that of dividing inventories into segments on a basis of annual dollar demand. Two annual dollar demand breakpoints, \$2,500 and \$25,000, have been identified which segment the inventory into three groupings—LDV, MDV, and HDV. Within the HDV classification some are recommended by an NICP and selected by higher headquarters for more selective management because of the importance of the item and the significant investment in inventory, or both. Again the selection emphasis is primarily a monetary one, but it may be based on combat essentiality, rapid deterioration or obsolescence, high security classification, or any of a number of other reasons, such as those listed in (1) through (4) below.

- (1) Items whose replenishment is almost entirely by repair (e.g., aircraft engines).

Table 1. Characteristics of Inventory Categories

Category	Annual Dollar Demand	Approx. Percent of \$	Approx. Percent of Items	Thoroughness of Analysis
LDV	< \$2,500	15	90	Cursory
MDV	\$2,500 to \$25,000	20	7	Moderate
HDV	> \$25,000	65	3	Intensive

- (2) Items with a large stable demand that might justify annual or multi-year contracting (e.g., tank tracks).
- (3) Items whose closely related, technical characteristics suggest economies might be gained through joint procurement (e.g., similar electronic components).
- (4) Sole source procurement items (e.g., magnetrons). A thoroughly comprehensive supply control study is required for these items.

b. Individual NICP's may find it desirable from time to time to select specific secondary items for special control emphasis on a temporary basis. These items may belong to any of the dollar demand inventory classifications, having been selected because of historical frequency of stockouts, a particular project man-

agement interest in the end item they support, or another suitable criterion. Once selected for special control emphasis, the asset position and requirements for these items should be reviewed more frequently and in more depth. If an habitual short stock position was the basis for more frequent review, an attempt should be made to identify the causative factors. This should be possible through analyses of lead time variations, nonrecurring demands, failure rates, and similar nonroutine impacts. Once the problem has been identified and corrected, or upon cessation of the critical period, these items should be deleted from the special management list and returned to normal control procedures.

c. Before moving to a discussion of control procedures, it is appropriate to summarize the characteristics of these inventory categories as shown in table 1.

Section IV. CONTROL PROCEDURES

27. Control Variables

a. Having divided the inventory of secondary items into classifications, i.e., LDV, MDV, and HDV items, for varying degrees of control emphasis, the problem remains of establishing specific control techniques and procedures. Several control variables exist. The more important control elements are listed in (1) through (5) below.

- (1) *The review frequency.* How often should the asset status be checked and an analysis made of requirements?
- (2) *The calculation procedure.* Modern scientific inventory techniques provide a basis for derivation of mathematical expressions that include a consideration of opposing costs and selected management decision rules. It is both possible and feasible to program computers to perform the bulk, if not all, of these calculations. Which calculations should be automated, and which, if any, should be performed manually (ones permitting incorporation of judgmental factors)?
- (3) *Depth of the requirement analysis.* In the Army supply system, many layers of command, multiple stockage points,

and several sources of data exist between the wholesale logistics level and the ultimate consumer. A more extensive analysis, one that considers all pertinent variables, will provide more meaningful and accurate information but will be more costly and time-consuming. How should the thoroughness of the analysis be related to the importance of the item?

- (4) *Input data.* Data has the source connotations mentioned above, and quantity and time parameters as well. How comprehensive should demand data be, and over how long a time period should it be collected?
- (5) *Reviews of procurement and rebuild quantities.* The action selected by a supply analyst upon completion of a supply control study may involve the expenditure of as little as a few hundred dollars or millions of dollars. How many reviews are required and at what level to insure the accuracy of the study and the decision (action) optimum in the context of the total supply system?

Table 2. Control Variables and Classification

Control Variable	Classification		
	LDV	MDV	HDV
Minimum Review Frequency	12 months	6 months	3 months
Type of Supply Control Study	All ADPS	All or part ADPS	Part ADPS
Depth of Study Review	Cursory	Moderate	Intensive
Depth of Requirements Analysis	CONUS net depot	CONUS net or major overseas depot	Major overseas depot
Quantity and Quality of Input Data	Least	More	More

b. Each of the above control variables was evaluated during the preparation of AR 710-45. The guidelines established in that regulation are summarized in table 2 and are discussed in the paragraphs that follow.

28. Review Frequency

a. Control of inventory focuses on two fundamental questions—(1) when to buy—the determination of the order point; and (2) how much to buy—the order quantity, economic or otherwise. The answers to each of these questions have a bearing on the determination of the length of time between successive reviews.

b. The decision to place a procurement order for replenishment stock is frequently determined by comparing the quantity of available

stock with a calculated quantity designated as a reorder point. Available stock can be defined, in the simplest case, as stock on hand and on order less dues-out (back orders). On the other hand, the reorder point quantity is composed (with continuous review of inventory status) of mobilization reserves, the expected usage over the procurement lead time and review cycle, and a safety level to provide for unpredictable demand. However, when review is periodic rather than continuous, a provision for the review cycle quantity must be included in the reorder point. The determination of reorder points is discussed in more detail in chapters 6 and 17. The important point to be understood at this time is that the length of the inventory status review cycle directly af-

fects the reorder point quantity and, in this manner, the size of the average inventory. The more frequent the review, the smaller the relative investment in inventory. To insure updating of requirements and stratification of assets for Financial Inventory Accounting (FIA) and budget purposes a complete supply control study will be made at least every 12 months on all items centrally managed. Within this concept however items with high demand rates and/or high unit costs should be reviewed more frequently to reduce average investment in inventory.

c. It should be noted, however, that modern data processing equipment with random access capabilities makes it possible and often economical to review assets against a number of control points (e.g., reorder point, retention level, minimum on-hand quantity) at the time of each transaction. In this instance, review can be considered as continuous, and the review time is effectively zero. When continuous and automated review procedures are practiced, review time becomes meaningless as a selective management control variable, and the review cycle allowance should be deleted from the computation of the reorder point.

d. The ADP equipment currently available at all NICP's permits inventory status comparisons on an essentially continuous basis (i.e., often daily and at least weekly). In brief, review provisions are to insure a thoughtful analysis of requirements and historical experience at sufficiently frequent intervals to prevent gross stock imbalances.

29. Manual Versus Computerized Calculations

a. Current regulations stipulate that supply control studies be performed by a computer for LDV items and may be automated for MDV and HDV items. However, the studies for HDV items must be reviewed by a supply analyst.

b. The obvious intent is that the effort, at least as measured by man-hours applied and the effect of the supply control decision, be proportional to the annual dollar demand and/or military essentiality of the item. The accompanying inference is that the skills and judgment that the analyst will apply during his review cannot be adequately programmed for

computer solution, and that subjective decisions are based not on the rules of computer logic but on full appreciation of the interrelated logistics and funding systems.

c. Automatic Data Processing System (ADPS) inventory control applications are discussed in some detail in chapter 15. Three points worthy of mention here are—

- (1) The answers supplied by computers are completely dependent upon the logic supplied by the programmer and the accuracy and relevancy of the input data.
- (2) Computer capabilities to handle greater quantities of more complex data are being advanced rapidly.
- (3) A computer can perform calculations much more rapidly and accurately than any human analyst.

These factors are certain to influence the future pattern of supply control studies as performed at NICP's.

30. Depth of Requirements Analysis

a. Two bases for requirements computations by inventory category have been established. The important features of these methods are shown in table 3.

b. It is apparent upon investigation that data collection and analysis costs are higher for the major oversea method than for the CONUS net depot method. The concept of selective management has been applied in the selection of these procedures. The expectation is, however, that decisions arrived at through the use of a more detailed method will result in inventory cost savings and/or improved performance that outweigh the cost of the additional effort.

c. Current practice at NICP's is to use the CONUS net depot method for almost all of the MDV items and to apply the major oversea depot method to HDV items. In both cases, the reason for current use of the lesser analysis is one of data limitations. Sufficiently good and timely data to permit application of a more refined method is a rarity. However, new reporting systems and procedures, such as The Army Equipment Record System (TAERS), may overcome this present limitation in the near future.

Table 3. Bases for Requirements Computation by Inventory Category

Basis	Used For	Asset and Demand Data	Assumptions
CONUS Net Depot	<ul style="list-style-type: none"> - All LDV - Most MDV - HDV with USASMC Approval 	CONUS depot assets and demand	In-transit, installation, and overseas depot levels in balance
Major Overseas Depot	<ul style="list-style-type: none"> - Selected MDV - All HDV 	CONUS and overseas depot assets, forecast requirements of both	Installation levels in balance

d. The important conclusion to draw from this discussion of asset and demand data analysis, in the context of the principles of selective management, is again that the effort should be proportional to the potential reward. While the Logistics Data Center (LDC), Major Item Data Agency (MIDA), and other data generating and disseminating media may improve the situation, the multilayer, long pipeline Army supply system reacts sluggishly to change at the present time. For this reason, it is difficult, if not impossible, to control stocks adequately with just one layer (CONUS net depot) of asset and demand data. On the other hand, additional information is costly and, in some cases, very difficult to obtain. As the system is currently functioning, the present bases for requirement computations appear to be a reasonable trade-off between accuracy and cost. Whenever good supplementary data are available, however, they must be taken into consideration.

31. Input Data

a. The sources of data relative to inventory classification have been discussed in the preceding paragraphs. The new questions to be

raised here are how much data should be used and how refined should it be.

b. In keeping with the selective management principle, it may be stated that the quantity and quality of statistical data to be accumulated and evaluated for any given item should be proportional to the importance or the dollar value of annual demands. Historical data are utilized primarily for the forecasting of future demand. The amount of data required is a function of the degree of sophistication applied in the forecasting technique. Forecasting techniques are reviewed in detail in chapter 5. Only a brief mention of these techniques will be made here to illustrate the necessary points.

c. Demand for a particular item will usually fluctuate widely from day to day and often from week to week. Demand data may be adjusted through the use of exponential smoothing techniques to give greater recognition to more recent demand history and less recognition to wide fluctuations in recorded demand. Analyses such as these permit a determination of whether the demand over a long period of time is trending up or down, demonstrating a seasonal demand, or remaining essentially constant.

d. Any reasonably sound analysis of demand data requires a year or more of historical information. In most cases trend and seasonal analyses should be based on at least 3 or more years of data. It becomes apparent that the data collected should be commensurate with the level of analysis warranted and practiced. It would be foolhardy, for example, to make a thorough analysis of seasonality in an LDV item and then procure a 2-year supply. Conversely, it would be inappropriate to ignore a discernible trend in an item with a high annual dollar demand. In summary, at least 2 years of historical data should be maintained for all items, more data should be collected for higher dollar demand items, and no meaningful available data for HDV items should be discarded.

e. It should be noted that not all data retained for analysis will necessarily be used in making forecasts. Quite frequently, as is discussed further in chapter 5, a relatively short span period is desirable in forecasting to achieve a sensitive response to a real trend in demand. For example, a detailed analysis of 3 years of demand data might reveal the existence of a clear-cut upward trend in demand. However, it may also be determined that this trend is best estimated by using a 6-month moving average.

32. Reviews of Supply Control Actions

a. Unfortunately, an opportunity exists to arrive at a wrong decision at the completion of both ADPS and manual supply control studies. Faulty input data is the most common cause of an improper ADPS-directed action, while a supply analyst is capable of making arithmetical mistakes as well as erring in subjective judgments. To avoid stockouts or an overabundance of inventory, it is important that these errors be discovered before the directed procurement, rebuild, or disposal action is implemented.

b. Errors can often be detected through a review process. The review function begins when the supply analyst checks his calculations. The supply analyst must review his actual recorded demands, unserviceable returns and deliveries from procurement and overhaul against past forecasts. This review will provide a measure of his past effectiveness in predicting future events. Based on this review, corrective action may be indicated to adjust computed future requirements and revise or expedite delivery of quantities on procurement or overhaul. This process then proceeds through the management layers of the NICP organization—Commodity Manager, Section Chief, Branch Chief, Division Chief, Director, and higher authorities, as appropriate. If the concept of selective management is to be applied fully, the thoroughness and frequency of these reviews should be proportional to the importance of the action indicated.

c. Several criteria for review procedures are possible. An obvious one is the classification of the item involved. LDV item studies could be spot-checked on a random sampling basis, a larger percentage of MDV item studies reviewed, and all HDV item studies examined. Another logical basis for review could be the dollar value of the directed procurement or rebuild action—the greater the dollars, the more thorough the review. A third basis might be the military essentiality of the item, and a fourth, the current status of back orders or recent history as to stockouts. It is possible to incorporate all of these criteria in a table, as that below, that designates the number (management levels) and nature (depth of analysis) of the reviews. (See table 4.)

d. The time and talents of administrators and analysts should be directed into activities of higher potential payoff. A formal structured review procedure is required to achieve this goal.

Table 4. Tabularized Review Procedure

Supply Control Study Characteristics	Reviewing Authorities						
	Commodity Manager	Section Chief	Branch Chief	Division Chief	Directorate Chief	NICP Chief or Deputy	Higher Hqtrs
Nonessential LDV items	2	3	-	-	-	-	-
Military-essential LDV items	1	2	3	-	-	-	-
Habitually out-of-stock LDV items	1	1	2	3	3	-	-
Nonessential MDV items	1	2	3	-	-	-	-
Military-essential MDV items	1	1	2	3	-	-	-
Habitually out-of-stock MDV items	1	1	1	2	3	3	-
HDV items, < \$25,000	1	1	2	3	-	-	-
" , \$25,000 to \$50,000	1	1	1	2	3	-	-
" , \$50,000 to \$100,000	1	1	1	1	2	3	-
" , \$100,000 to \$250,000	1	1	1	1	1	2	3
" , \$250,000 to \$500,000	1	1	1	1	1	1	2
" , > \$500,000	1	1	1	1	1	1	1
<p align="center"><u>Review Procedure Code</u></p> <p>1 - Detailed review of study and approval 2 - cursory review and approval 3 - Spot-check random sample of studies</p>							

Supply control studies may be reviewed to determine that the arithmetic used is accurate or that factors used to determine requirements are the correct ones. The first reviews should never

have to extend beyond the first level of supervision. It is the review of factors and the judgment applied which is important.

CHAPTER 4

COLLECTION AND ANALYSIS OF DATA

Section I. GENERAL

33. Importance of Data

To a considerable extent, the success or failure of the Army inventory management system depends upon the accuracy and relevancy of the historical supply data collected. In order to manage items in the Army supply system on a selective basis, demand information must be collected for each item in the system. To forecast future demands accurately, trends must be recognized and demand fluctuations must be analyzed and interpreted. In addition, troop densities, item essentiality, and the entry of new items into the system must be taken into account. The use of incorrect data must be held to a minimum, as it will result in distortions and inaccuracies in the forecasting of future requirements.

34. General Classes of Data

a. The Army collects and utilizes three general classes of supply data— issue data; demand data; and consumption data.

- (1) Issue data are supply history data that indicate a transfer of materiel to an authorized requisitioner. Issue data are the most readily available type of information in the Army supply system, because issues represent a clearly identifiable physical transfer and because, in general, accurate records are maintained. These data are usually supplied in a consolidated report form and are generated wherever issues are made (e.g., by depots, stations, and organization units).
- (2) Demand data are those data that measure valid requests for materiel. These data are valuable in that they reflect actual requirements more ac-

curately than other forms which may be clouded by out-of-stock conditions and the related use of substitute items. It should be noted, however, that demand data do not normally measure consumption.

- (3) Consumption data measure materiel actually consumed and therefore assist in forecasting future rates of replenishment. These data will become more significant in supply control activities as improved asset reporting systems (such as TAERS) are expanded to cover additional items.

b. Issue data do not present a true picture of what materiel is actually desired and, if used without adjustments, will result in inflated stock levels for substitute items and reduced levels for desired items. Demand data, on the other hand, require a more complex system for collection and reporting since they attempt to segregate the actual items demanded from the substitute items that may have been issued. Because of collection problems, demand data are often accurate only at the level at which they are generated, and the true demand beyond that point is difficult to determine. Consumption data have to be secured entirely at the user end of the materiel pipeline, and therefore their collection is difficult. However, when consumption data are available, they yield a clearer picture of actual usage than either of the other two general classes of data.

35. Types of Data Source Documents

a. The types of data source documents collected and used by the Army have been described in such publications as AR 725-50 (MILSTRIP) and TM 38-750 (TAERS). The

documents used to transmit data can be subdivided into two general groups—"issue or release" documents; and "informative" documents. The following types of supply documents for "issue or release" of materiel are authorized to be received and processed by the source of supply:

- (1) *Requisition*. A basic document used to requisition materiel such as the DD Form 1348 punched card for "manual" transmittal, or the DD Form 1348m on punched card for machine transmittal.
- (2) *Referral order*. An order used between depots, inventory managers, or other managers in an established supply distribution system for the purpose of passing correctly routed requisitions for continued supply action when the initial activity cannot fill the demand due.
- (3) *Supply directive*. A document by which an inventory manager (with proper authority) creates a requisition for release of materiel to a consignee without the necessity for the preparation and submission of a requisition.
- (4) *Passing order*. A document by which an erroneously routed requisition is rerouted to the proper source of supply, assuming information regarding the current source of supply is readily available.
- (5) *Materiel release documents*.
 - (a) *Materiel release order*. A document by which an NICP directs the release of materiel from a nonaccountable storage site located at another installation.

- (b) *Materiel release denial*. A document by which a storage activity notifies the accountable officer of a negative action (warehouse refusal) on the order releasing materiel.

- (6) *Redistribution order*. A document that directs the release of materiel to another supply distribution activity within the same supply complex.

b. The following types of "informative" supply documents are authorized to be received and processed as input by the source of supply:

- (1) *Follow-up form*. An inquiry as to the action taken on a requisition previously submitted.
- (2) *Cancellation*. A total or partial discontinuance of supply action requested of and confirmed by the supplier.
- (3) *Materiel release confirmation*. A document by which a nonaccountable storage site notifies the originating accountable point of positive supply action taken on Materiel Release Order.
- (4) *Adjustment*. A document used by storage points to submit source of information to accountable activities for adjustment of accountable records, and used by accountable activities to process internal adjustments to accountable records.
- (5) *Others*. Other "informative" documents include Shipment Detail, Supply Status, Shipment Status, Reply to Follow-Up, and Materiel Receipt Cards.

Section II. SOURCES OF DATA

36. General

a. Each of the NICP's exercise a firm control over the activities of the distribution depots under its jurisdiction. The individual NICP allocates newly procured stock among depots and dictates what response the depots will make to valid supply requisitions. Requisitions

are received by the NICP's from several sources.

- (1) CONUS Installations
- (2) Oversea ICPs
- (3) MAP countries
- (4) Other services

- (5) Contractors
- (6) Self-initiated.

b. When "demand" data, in the form of requisitions, reach the NICP's at the top of the multi-echelon system, they are often distorted. Requisitions are used to replenish stocks actually consumed as well as to build up levels at stockage locations. For this reason, replenishment requisitions represent both actual consumption of secondary items and forecasted consumption over some future period. Thus, the requisitions that are used to forecast demand are themselves made up in large measure of lower echelon forecasts. These data can then be expected to be quite different from actual failure data or true parts consumption data. Analyses of demands at the NICP level should proceed with this important fact in mind.

37. Analysis of Data

a. A further look at the types of data available for analysis discloses additional problem areas. For example, reductions in inventory, as indicated in a transaction report, are not always the result of a filled demand. Indeed, the stock balance, disposal, or transfer adjustments listed in such reports often create a discrepancy between issue data and available demand data which, in turn, requires a detailed analysis.

b. A knowledge of the relationship between issues of known substitutes and actual demands for a preferred item assists in computations when a wide variance in historical data arises. If the pattern indicates increased issue of the substitute item and decreased issue of the preferred item, the combined demand should serve as a demand equivalent for projection. Care must be exercised to assure that increased back orders are indeed indicative of a trend or that substitutions can be truly interpreted as a legitimate demand for the item being studied and are not an actual demand against the substitute item in its own right.

38. Records and Reports Used for the Transmittal and Storage of Data

The implementation of TAERS for a selected group of items has introduced new rec-

ords that provide additional demand, issue, and consumption data. Some of these records, which are described in detail in TM 38-750, are listed in *a* through *e* below.

a. *Operational Records.* These records facilitate organizational control of operators and equipment, operational planning, and optimum utilization of equipment. An example of an operational record that would be useful to supply management personnel is the Equipment Utilization Record (DA Form 2400).

b. *Maintenance Records.* These records are established to control maintenance scheduling, inspection procedures, and repair workloads. Certain records are designed to permit prompt analysis for causes of equipment failures, mortality rates of components, and supply support requirements. Examples of maintenance records that would be useful to supply management personnel are the following:

- (1) *Materiel Readiness Report (DA Form 2406).* A report that provides information regarding the readiness status of equipment in the hands of using organizations.
- (2) *Maintenance Request (DA Form 2407).* A source document for maintenance data collection.

c. *Equipment Historical Records.* Historical records for individual items with regard to the receipt, operation, maintenance, modification, transfer, and disposal of equipment. Examples of records in this group that contain information of use to supply managers include—

- (1) *Equipment Daily or Monthly Log (DA Form 2408-1).* A daily or monthly record of operation for specified items of equipment.
- (2) *Equipment Maintenance Record—Organizational (DA Form 2408-3).* A record of maintenance services, inspections, and repairs requiring parts usage at the organizational level. A method of recording and reporting status of equipment availability and serviceability.
- (3) *Weapon Record Data (DA Form 2408-4).* A continuous record of firings and other related service life data pertaining to weapon tubes.

Table 5. Data Sources Subdivided According to Dollar Value Classifications

Data essential to supply control	High dollar items (major over-sea depot method)	Medium dollar items (CONUS net depot method)	Low dollar items (CONUS net depot method)
1. Total recurring and nonrecurring demands on continental United States from worldwide (one total)			X
2. Recurring demands on continental United States as follows:			
a. Total worldwide (one total)		X	
b. USARPAC	X		
c. USAREUR	X		
d. CONUS and other oversea (one total)	X		
e. CONUS other oversea separately	X (1)		
3. Nonrecurring demands on CONUS as follows:			
a. Total worldwide (one total)		X	
b. USARPAC	X		
c. USAREUR	X		
d. CONUS and other oversea (one total)	X		
e. CONUS and other oversea separately	X (1)		
4. CONUS depot stock status to include--			
a. On hand--			
(1) Serviceable	X	X	X
(2) Unserviceable-repairable	X	X	X
b. Dues out	X	X	X
c. Dues in	X	X	X
d. Total returns of serviceable	X	X	X
e. Total returns of unserviceable	X	X	X
5. Major oversea depot stock status to include--			
a. On hand	X		
b. Dues out	X		
c. Dues in	X		
d. Requisitioning objective	X		
e. Demands on oversea depots	X		
f. Total returns of serviceable	X		
g. Total returns of unserviceable	X		
6. CONUS depot safety level	X	X	X
7. Production lead time--			
a. Current	X	X	X
b. Post D-day (may be estimated)	X	X	(1)
8. Administrative lead time	X	X	X
9. Delivery lead time	X	X	X
10. Reorder point	X	X	X
11. Replacement factor	X (1)	(1)	(1)
12. Intransit to oversea depots	X		
13. Schedule of repair of unserviceable stocks on hand	X	X	X
14. Repair cycle time	X	X	X
15. In-use density of end items or hours of operation, or troop strengths or other program bases, as applicable, for the base period and programmed for 3 succeeding fiscal years--			
a. Total worldwide		X	
b. USARPAC	X		
c. USAREUR	X		
d. Other oversea (separately)	X (1)		
e. CONUS (separately)	X (1)		
f. CONUS and other oversea (one total)	X (1)		
16. In-use density of end items, or hours of operation, or troop strengths, or other program bases, as applicable, through the required mobilization planning period	X	X	(1)
17. Installation stock status	X (1)		
18. Authorized allowances	X (1)		
19. In hands of troops	X (1)		
20. End item application (for repair parts only)	X (1)	X	X

(1) Optional

- (4) *Equipment Maintenance Record—Support Echelons (DA Form 2408-6)*. A historical record of support and depot maintenance performed on equipment.
- (5) *Equipment Transfer Report (DA Form 2408-7)*. A report for worldwide inventory control of specific equipment.
- (6) *Historical Record for Aircraft (DA Form 2408-15)*. A record of significant historical data for an aircraft from introduction into inventory to retirement of the aircraft.
- (7) *Equipment Maintenance Log—Consolidated (DA Form 2409)*. A complete maintenance history of an item of equipment.
- (8) *Component Removal and Repair/Overhaul Record (DA Form 2410) and (Transaction Report) (DA Form 2410-1)*. These forms provide a record and report of all aircraft engines, specific aircraft components, recoverable combat vehicle engines, and selected recoverable missile components. They provide commanders at commodity management levels with data essential for effective management and field commanders with information relative to the serviceability status of uninstalled recoverable components.

d. Ammunition Records. Munitions records

and procedures are prescribed to enhance the control and status reporting of munitions.

e. Calibration Records. Calibration records and procedures are prescribed for the control of this function for Army equipment.

39. Tabular Summary

a. A tabular summary of data sources subdivided according to dollar value classifications is presented in table 5.

b. Recurring demands are demands of a repetitive nature made to replenish materiel consumed or worn out in operation. Nonrecurring demands refer to demands made on a "one-time" basis to provide initial stockage allowances, to meet planned programmed requirements, and to meet one-time projects or maintenance requirements.

c. Depot stock status refers to the overall stock position of depot inventories at a particular point in time. This includes serviceables, repairables, dues-in, dues-out, and total returns.

d. All of the various parts of procurement lead time are discussed in chapter 6 in addition to reorder points, in-transit shipments, safety levels, and authorized allowances.

e. Schedules of repair of unserviceable stocks on hand and repair cycle times are discussed in chapter 11.

f. Program change factors are discussed in paragraphs 41 through 43.

Section III. INTRODUCTION TO FORECASTS

40. Accuracy of Forecasts

a. The accuracy of a forecast can be measured by the degree of deviation between actual and forecasted demand. As mentioned throughout this manual, there are relative cost penalties associated with stock shortages and overages. A method exists for minimizing the expected sum of these penalties.

b. The two ways in which risks associated with shortages and overages can theoretically be reduced are—

- (1) By improving the accuracy of the

forecasting system. It should be recognized, however, that in some cases a great deal of cost and effort may be required to devise a truly optimal forecasting system.

- (2) By shortening the lead time. In actual practice, this may be impossible or impractical.

c. The best opportunities for improving an existing forecasting system lie in—

- (1) The improvement of the data itself (discussed earlier).

- (2) More accurate determination of the statistical distribution from which the data originated (ch 16).
- (3) Choosing the most appropriate fore-

casting smoothing model, that is, one that minimizes the forecast error.

Note. Smoothing techniques are discussed in detail in Chapter 5.

Section IV. PROGRAM CHANGE FACTORS (PCF)

41. Definition

Program change factors are multipliers used to alter a forecasted recurring demand requirement on the basis of planned changes in hours of operation, troop population, and end item densities. These factors are based on known and controllable changes in requirement. It should be made clear that program change factors are applied only after a forecast has been made. For this reason, their effectiveness in correctly indicating future requirements is dependent on the accuracy of the original forecast.

42. Example

If during a base period (one year) there had been 100 units of a particular weapon system in the hands of troops and planned changes indicate that this density would be increased to 120 units during a future quarter, then the PCF is—

$$\frac{120}{100} = 1.20$$

In turn, if the average quarterly demand (AQD) for a secondary item that supports this

weapon system, based on a moving average of the eight most recent quarters, is forecasted to be 20 units, then the adjusted recurring demand for the future quarter will be—

$$20 \text{ units} \times 1.20 = 24 \text{ units}$$

43. Application

a. It is recognized that periodic changes in a PCF, as in the case of troop strength, may be so small as to be negligible and would, therefore, have no appreciable effect on the demand forecast. Nevertheless, it is considered that routine application of PCF's is important to assure that the supply system will respond promptly to any significant requirements increase, so that the military peacetime, limited war, and all-out mobilization needs will be adequately supported.

b. Whenever the use of a PCF will clearly have no appreciable effect on the demand forecast, a value of 1 should be assigned as the factor. In effect, this is equivalent to bypassing the application of the PCF.

CHAPTER 5

FORECASTING TECHNIQUES

Section I. GENERAL

44. Definition

This chapter is concerned with the forecasting responsibilities of supply managers. In the context of this manual, forecasting means the use of historical data and mathematical computations to estimate future demands. At the NICP level, forecasted requirements are based upon reported demand data. At higher echelons, budgets and financial plans are based upon forecasts of future end item densities, troop strengths, and political environments.

45. Basic Criteria for Forecasts

In order for a forecast to be valid, its mathematical formulation should reflect the following two properties:

- a. It should be able to respond rapidly to real changes in averages
- b. It should not be unduly influenced by the presence of random variation.

In other words, a good forecast should be reasonably stable in the presence of chance fluctuation.

46. Demand Patterns

a. Before undertaking a study of the various methods used in forecasting, it is necessary to define and illustrate various types of demand patterns. In general, historical demand patterns for secondary items (and for that matter, any stocked item) will fall into one of the following four classifications:

- (1) *Constant demands.* Figure 10 illustrates an example of a relatively constant demand. It could, for instance, represent the demand for canvas jeep tops or any of many commonly stocked items. The basic characteristic of a constant demand pattern is the tendency of the demand to remain at a given level. In

addition to the overall average demand, however, some variation will still exist from month to month. These fluctuations do not follow any recognizable pattern, but are random. Variability is usually superimposed on every demand pattern. In this case, the problem of forecasting is to determine what the true average demand is and to identify the range of variability about this mean value.

- (2) *Secular trends.* If the demand for a stocked item shows a consistent linear or higher order trend (upward or downward) over a relatively long period of time, this condition is referred to as a secular trend. The trend may indicate that the demand is increasing or decreasing. Figure 11 illustrates two trends of this type; one is linearly increasing while the other is linearly decreasing. It should be noted that secular trends are sometimes difficult to identify. If, for example, the amount of random variation in the demand data were greater than or equal to the underlying trend, this secular trend would tend to be obscured.
- (3) *Cyclical patterns.* Demand data can also exhibit a cyclical pattern. This type of demand response is characterized by a number of peaks and valleys that tend to occur at regular intervals. Figure 12 illustrates a hypothetical cyclical demand pattern for a type of vehicle antifreeze. The analysis of cyclical patterns can lead to the development of specialized forecasting models that describe the cycle in terms of trigonometric and transcendental functions. These models normally require

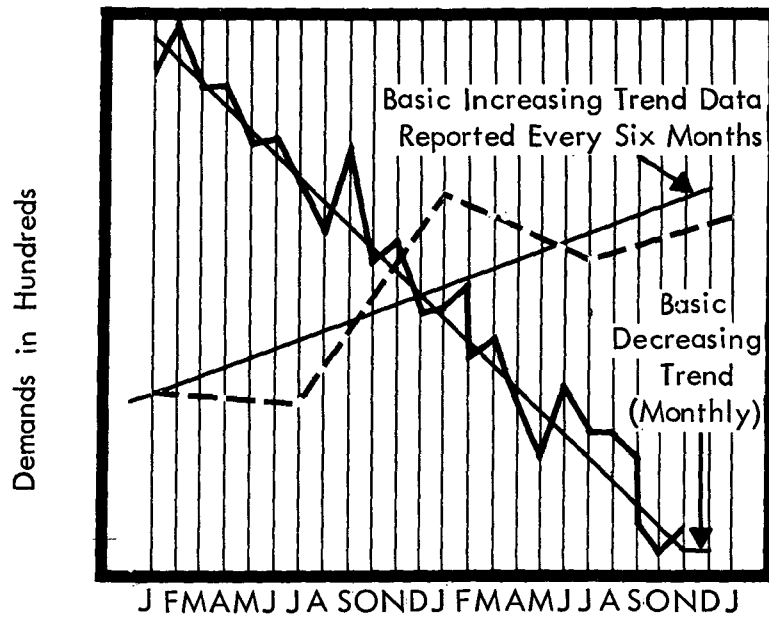


Figure 10. The monthly demand of an item exhibiting a constant demand pattern with superimposed random variation.

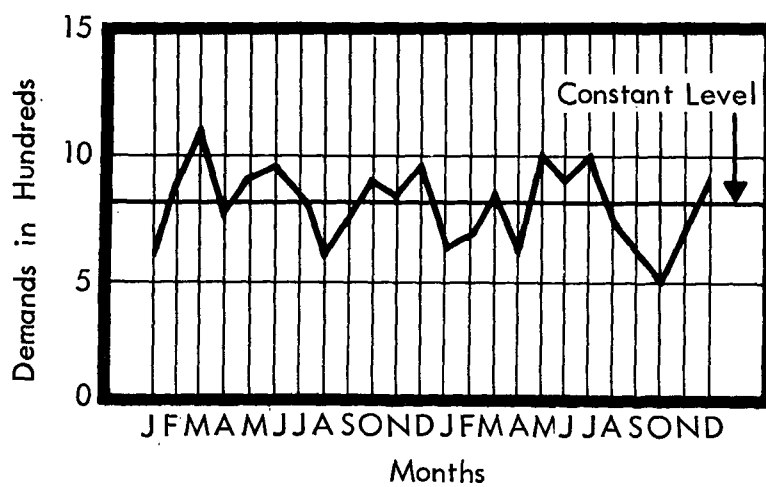


Figure 11. The monthly demand of two items exhibiting a linear trend with superimposed random variation.

sophisticated analytical procedures. While all demand analysis is complicated by the presence of random variation, the problem is accentuated in the case of attempted identification of cyclical patterns. When random variability is excessive, it may not be possible to identify the underlying cycle.

(4) *Seasonal Patterns.*

- (a) Seasonal patterns are a particular type of cyclical demand where the

peaks and valleys follow a definite pattern from year to year. In order for demand data to be recognized as exhibiting a seasonal pattern, demand peaks should be considerably greater than the average demand and the stocked item should have a rational basis for seasonality. The latter condition requires an identifiable and logical reason for the observed seasonality. The antifreeze data given in

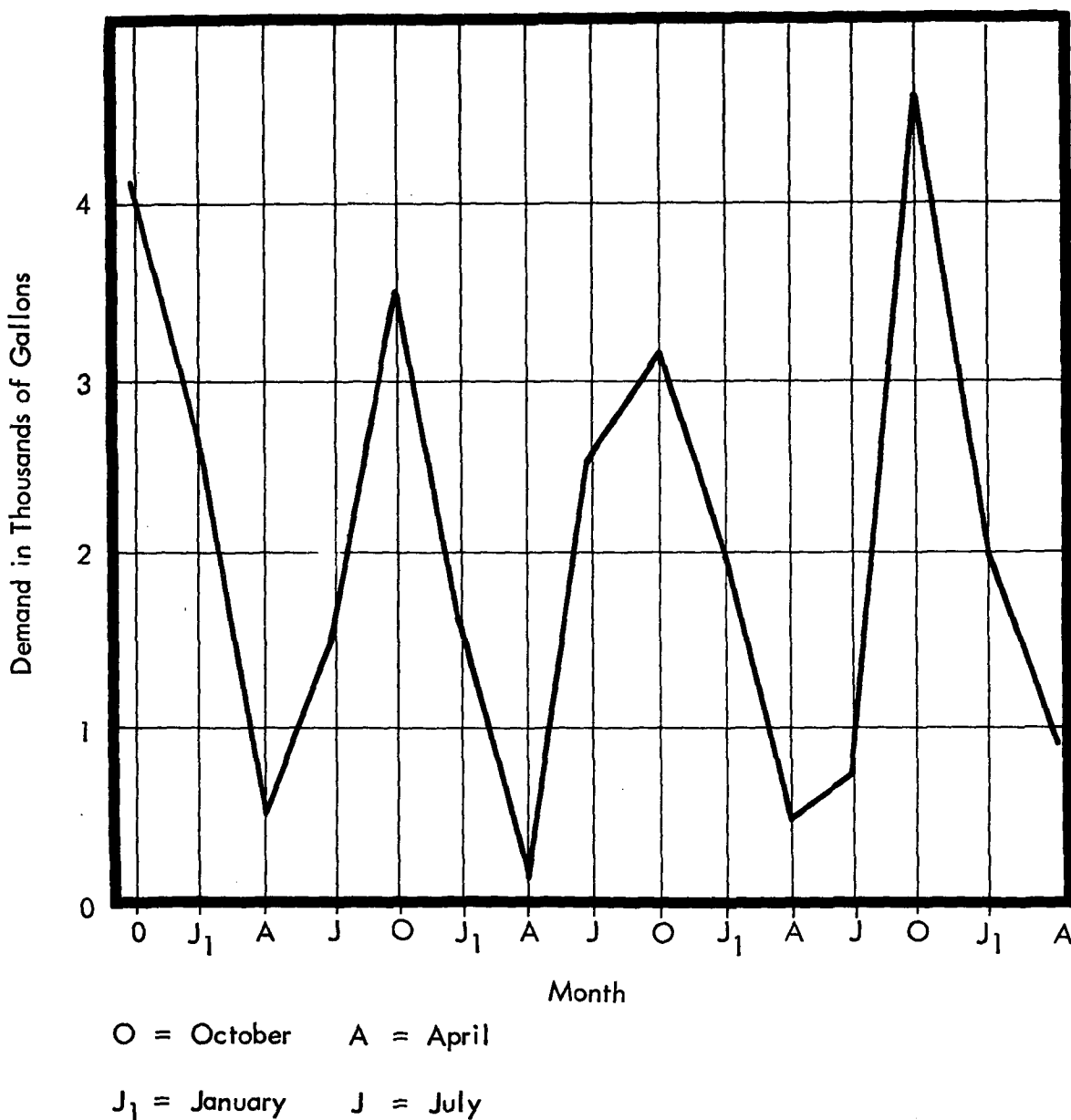


Figure 12. Demand for vehicle antifreeze reported quarterly illustrating both a cyclical and seasonal pattern with random variation.

figure 12 are representative of an item that demonstrates a seasonal pattern.

- (b) Except for a few noteworthy examples, such as cold weather items, few Army secondary items evidence strong cyclical or seasonal demand patterns. Even in some cases where seasonality exists, the size of Economic Order

Quantities (EOQ's) or the length of the supply pipeline renders these effects meaningless at the NICP level. For this reason, the remaining sections of this chapter emphasize the identification and handling of secular trends. However, chapter 10, in its discussion of ADPS assisted supply control studies, contains an example of a computerized test for seasonality.

Section II. FORECASTS BASED ON ENGINEERING ESTIMATES

47. General

During the period of initial provisioning of secondary items, there may be no history of demands upon which to base a forecast. In this situation, management decisions are based primarily on the manufacturer's or engineering estimate of the reliability of the item under war-time conditions. The reliability estimates, in turn, are grounded on an analysis of the design features of the item coupled with a knowledge of the expected operating stresses to be placed on the equipment. Data of this type are usually reported in terms of failure rates. For example, MIL-HDBK-217 (Reliability Stress and Failure Rates for Electronic Equipment) is a military standardization handbook containing numerous illustrations of failure rates for electronic equipment. TAERS is designed to provide more actual consumption data on high dollar value items (e.g., aviation and missile parts). It currently excludes most repair items. Should more consumption data become available through an expansion of TAERS or a similar system, it would then be possible to base forecast estimates on actual field failure rates as well as on demand data. Thus, reliability estimates and their associated methodology may play a greater role in future forecasting schemes.

48. Simple Averaging

When a new piece of equipment is first available for distribution, there will be no demand history suitable for use in forecasting. However, if there is available experience with similar parts (e.g., substitute or superseded items), this information may be used. By analyzing and extrapolating data on similar parts currently or previously in use, and by averaging the demand history of all

such items, a rough initial forecast can be made for the new item. Forecasts of this type are often expressed on a density basis as the ratio of demands per hundred items in use. In addition, if some further information is available indicating approximately how much longer the newer item can be expected to remain in use before requiring replacement or repair (improved reliability), the forecast may be adjusted by a factor to reflect this improvement and may be made more accurate.

49. Engineering Estimates

a. The manufacturer and the design engineer will attempt to specify a probability of failure for each line item before it is introduced into service. Their objective is to determine the reliability of each item involved. In this analysis, they are interested in determining normal wearout times as well as the probability of random failure.

b. In order to obtain a good estimate, they generally have to determine the failure rates of the end item and of the parts making up each item. This can be accomplished either by testing, and thus experimentally determining the failure rate, or by design considerations. When the failure rate of an item has been specified in terms of known operating conditions, it can be used to estimate the mean-time-to-failure and the proportion of failures expected during a specified time interval.

c. Table 6 contains failure rates for film resistor MIL-R-10509 and their relationship to ambient (air) temperature and the ratio of operating to rated wattage.

As has been done in this table, failure rates are usually expressed in percent per 1,000 hours. In contrast, repairable parts for aircraft are computed on a 300 hour interval, this being the average

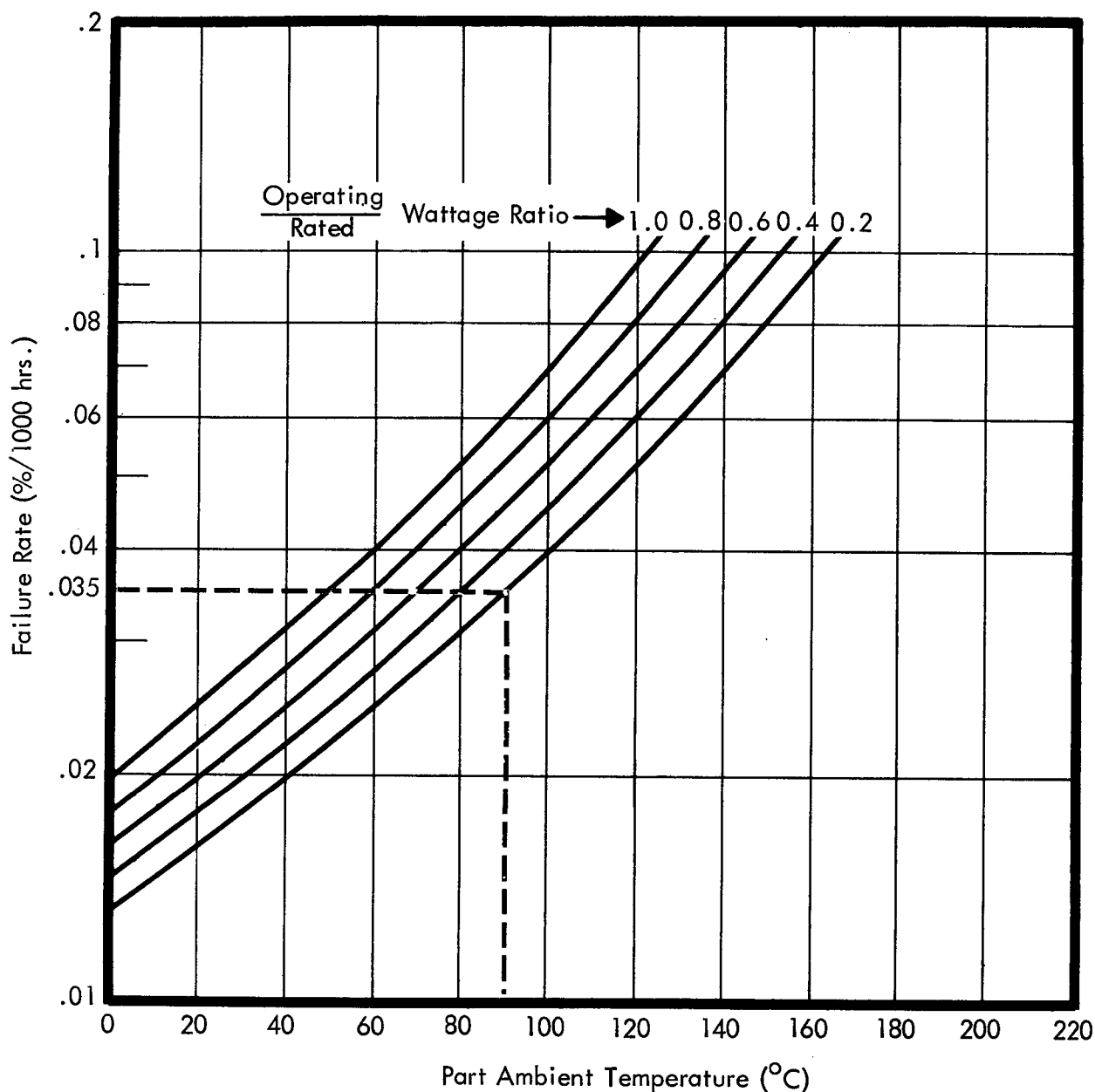


Figure 13. Failure rates for MIL-R-10509D film resistors, temperature range C, E, and F (relative humidity less than 60%) (see notes to table 6 for proper use of this fig.)

annual flying time for Army aircraft. Figure 13 contains a graphical representation of the same data. (This material has been extracted from MIL-HDBK-217.) When the operating conditions are not exactly equal to the values given in the table, the desired failure rates can be interpolated from the graph.

d. Sometimes a modification or adjustment must be made in the tabled failure rates to reflect restrictive operating conditions. In this case, the necessary adjustment factors and the methods

for modifying the failure rates are also available in the Military Standardization Handbook. Since the accuracy of these failure rates is usually not specified, however, it should be recognized that forecasts of this type may be only rough estimates of the possible usage.

e. The use of engineering data in demand forecasting can best be illustrated with an example. Assume that a depot receives a supply of a new type of resistor, and they are told to forward these to field installations as replacements for a less

Table 6. Failure Rates (%/1000 hrs) for MIL-R-10509D Film Resistors, Temperature Range C, E, and F (Relative Humidity Less Than 60%)

Ambient Air Temperature (*C)	Ratio of Operating to Rated Wattage									
	.1	.2	.3	.4	.5	.6	.7	.8	.9	1.0
0	.012	.013	.014	.014	.015	.016	.017	.018	.019	.020
5	.013	.014	.014	.015	.016	.017	.018	.019	.020	.021
10	.014	.014	.015	.016	.017	.018	.019	.020	.021	.022
15	.014	.015	.016	.017	.018	.019	.020	.021	.022	.023
20	.015	.016	.017	.018	.019	.020	.021	.022	.023	.024
25	.016	.017	.018	.019	.020	.021	.022	.023	.024	.026
30	.017	.018	.019	.020	.021	.022	.023	.024	.026	.028
35	.018	.019	.020	.021	.022	.023	.024	.026	.028	.029
40	.019	.020	.021	.022	.023	.024	.026	.028	.029	.031
45	.020	.021	.022	.023	.024	.026	.028	.029	.031	.033
50	.021	.022	.023	.024	.026	.028	.029	.031	.033	.035
55	.022	.023	.024	.026	.028	.029	.031	.033	.035	.038
60	.023	.024	.026	.028	.029	.031	.033	.035	.038	.040
65	.024	.026	.028	.029	.031	.033	.035	.038	.040	.043
70	.026	.028	.029	.031	.033	.035	.038	.040	.043	.046
75	.028	.029	.031	.033	.035	.038	.040	.043	.046	.049
80	.029	.031	.033	.035	.038	.040	.043	.046	.049	.052
85	.031	.033	.035	.038	.040	.043	.046	.049	.052	.056
90	.033	.035	.038	.040	.043	.046	.049	.052	.056	.060
95	.035	.038	.040	.043	.046	.049	.052	.056	.060	.065
100	.038	.040	.043	.046	.049	.052	.056	.060	.065	.070
105	.040	.043	.046	.049	.052	.056	.060	.065	.070	.076
110	.043	.046	.049	.052	.056	.060	.065	.070	.076	.082
115	.046	.049	.052	.056	.060	.065	.070	.076	.082	.089
120	.049	.052	.056	.060	.065	.070	.076	.082	.089	.096
125	.052	.056	.060	.065	.070	.076	.082	.089	.096	.105
130	.056	.060	.065	.070	.076	.082	.089	.096	.105	
135	.060	.065	.070	.076	.082	.089	.096	.105		
140	.065	.070	.076	.082	.089	.096	.105			
145	.070	.076	.082	.089	.096	.105				
150	.076	.082	.089	.096	.105					
155	.082	.089	.096	.105						
160	.089	.096	.105							
165	.096	.105								
170	.105									

Resistor Rating in watts	f_1
1/8	1.5
1/4	1.2
1/2	1.0
1	.9
2	1.2

Resistance Value in Ohms	f_2
Up to 100K	1.0
100K to 1 Meg.	1.2
1 Meg. to 10 Meg.	1.5
10 Meg. to 30 Meg.	2.0

Note: The final failure rate is obtained by multiplying the value obtained above by $f_1 \times f_2$ as given in these tables.

reliable resistor. Using engineering estimates of the failure rates at specified operating conditions, the NICP is interested in forecasting the number of replacements required 1,000 hours after the initial shipment. Assume further that 500,000 resistors were sent to the field along with a request for immediate installation. What is the expected number of failures (ENF) after 1,000 hours of use? For this example, assume that the estimated average ambient air temperature is 90° C. and the ratio of operating to rated wattage, 0.2. (See table 6 and fig. 13 for selection of .035 percent failure rate.)

- (1) $ENF = \text{Number units operating} \times \text{rate}$
- (2) $ENF = 500,000 \times .00035 \text{ per } 1,000 \text{ hours}$
- (3) $ENF = 175 \text{ resistors will have failed.}$

This problem is oversimplified, of course, since each resistor will not have received the same use. For this reason, the failure rate is only an estimate of the true failure rate. It does, however, provide some useful information on which to base a demand forecast. Once data on the actual number of demands are available, demand data should replace engineering estimates.

50. The Actuarial Method

a. A recent report from the USAMC Inventory Research Field Office, Frankford Arsenal, includes a discussion of the actuarial technique developed for the U.S. Air Force.

b. This approach has given good results in forecasting future failures for a selected group of high-cost aircraft components. It promises to be particularly useful in cases where failures and removal rates depend on the age of an item (measured from the time the item was placed into service). In this instance, actuarial type analysis can provide—

- (1) A true picture of the component reliability by considering both the failures and the nonfailures over a specified period; and
- (2) Better estimates of the component survival probabilities or failure rates.

c. Actuarial type analysis depends upon measurement of a multiplicity of events. The validity of the analysis is in direct relationship to the number of events analyzed. When issues per year are few, efforts expended on actuarial analysis tend to be unrewarding.

51. Transition to Demand Data

Whatever method is used to estimate stockage requirements for a new item when it first enters the supply system, it will normally be discarded when an adequate amount of actual demand data is available for forecasting purposes. How long it will take to accumulate sufficient demand data will depend, of course, on distribution densities and usage rates; but, under normal circumstances, a data collection period of at least 12 months will be required.

Section III. SMOOTHING TECHNIQUES

52. General

a. The process of removing random variation from an ordered series of demand data is referred to as "smoothing." The smoothing technique used should reflect a consideration of the basic characteristics of a particular stocked item or, if a generalized inventory model is being used for a group of items, the characteristics of the group. In demand forecasting of secondary items, a constant or a secular demand pattern is most often encountered. Seasonality and cyclical patterns, although possible, are generally not observed. Even when cyclical patterns are present in the data, they are usually obscured by large amounts of random fluctuation.

b. Before proceeding to a detailed discussion of some common demand forecasting techniques,

certain precautionary comments are necessary. For instance, forecasting models should not be used over an extended period of time without some appropriate monitoring procedure. The indiscriminate use of a model or programmed forecasting routine can often lead to bad forecasts. The major reason for this difficulty is that the models currently in use cannot adequately cope with long histories of low demand or many periods with zero demands. They are also influenced by the choice of an initial forecast. This is particularly true of new items entering the inventory. Also, most models lack a mechanism for automatically adjusting the smoothing constants as data are observed to become more or less variable (although techniques for selecting the best initial smoothing constant are currently applied). Finally, the

models considered in this chapter do not usually incorporate a consideration of the possibility of a catastrophic event (i.e., unusually high demands placed on the supply system). The problems of handling catastrophic events should be considered separately from the basic problems of forecasting recurring and nonrecurring demands.

c. Although the above shortcomings are inherent in current demand forecasting techniques, these techniques nonetheless provide useful tools for management at the NICP level. The essential steps in a good forecasting scheme are to select the best demand model, to use the appropriate arithmetic procedure, and, finally, to continue monitoring the system. In the following paragraphs a number of demand models will be considered, and the currently used forecasting procedures will be discussed and illustrated.

53. Basic Demand Model

a. Before examining these forecasting techniques, it will be instructive to consider an elementary demand model. Assume a situation in which the demand data are believed to follow a constant trend; that is, the best estimate of an expected demand is a constant value plus or minus some variability about this average. For example, if the average demand was for 10 units per month and the maximum and minimum observed demands had been 12 and 8 units, respectively, the demand could be expressed as 10 ± 2 . This can be expressed in the following mathematical form:

$$X_t = a + E_t$$

where

X_t = the observed demand at time t

a = the constant demand or the true average demand

E_t = the random component corresponding to the observation time t . This represents the "noise" in the process.

b. This model is appropriate when the basic demand pattern is observed to be similar to that given in figure 10 (i.e., when the observations appear to oscillate about some central value). The average in this example is approximately 8 units per month. To specify this model more exactly, some knowledge of the nature of the variability is required. If the deviations about the constant demand are truly random, E_t can be assumed to have an average value of zero and a

variance of σ_E^2 (The variance, often represented by sigma squared, is an important statistic. It is discussed in ch 9 and 16.) A basic model of this type is implied when moving averages or single exponential smoothing is used as a forecasting technique.

54. Moving Averages

a. One method of forecasting demands is referred to as moving averages. The process consists of averaging together N data points (or demand periods, such as months or quarters) starting at some specified time t . Suppose the monthly demand records for a particular item were available for 6 consecutive months and were 5, 7, 3, 6, 6, and 4. What would be a forecasted demand for the fourth month based on a simple average of the first 3 months? The average would be calculated as follows:

$$\frac{5+7+3}{3} = \frac{15}{3} = 5.$$

The forecasted demand for the fourth month would then be 5. This compares favorably with the observed value of 6. Symbolically, the moving average can be written

$$X = \frac{X_t + X_{t-1} + \dots + X_{t-N+1}}{N}$$

where

X_t = the observed demand at time t

X = the average and the forecast for the $t+1$ time period

N = the number of observations used in computing the average.

In this example, time t was 3 months, X_t was three units, N was three demand periods, and the two earlier demand values were 7 and 5. The rate at which X responds to changes in the basic constant demand structure depends on the choice of N . When N is small, the moving average will respond quickly to changes in the basic demand level; on the other hand, when N is large, the moving average will respond slowly to changes in "a" (the constant demand or the true average demand).

b. For a more complete example, consider the demands presented in table 7. A graphical representation of these demands covering a 2-year reporting period is given in figure 14. Table 8 illustrates the arithmetic procedure for obtaining

Table 7. Monthly Demand Data Recorded Over a 2-Year Period for a Hypothetical Stocked Item

Date (Months)	Demand (Units)	Date (Months)	Demand (Units)
1	15	13	34
2	10	14	38
3	12	15	44
4	17	16	41
5	19	17	39
6	18	18	46
7	24	19	49
8	22	20	59
9	24	21	55
10	29	22	58
11	35	23	65
12	33	24	69

forecasts based on an 8-month moving average ($N=8$) for these selected demand records.

55. Exponential Smoothing (Single)

a. An alternative and preferred procedure is available for handling the demand data presented in table 7 and figure 14. This technique uses a combination of the previous forecast and the most recently observed demand to obtain a revised forecast for the next time interval. This technique is called exponential smoothing because less weight is given to older demand data despite the fact that all previous data are included in the process of obtaining the new forecast. A constant, α , called the smoothing constant, is used to adjust the difference between the observed demand and the previously computed forecast (i.e., the forecast = α (observed demand) + $(1-\alpha)$ (old forecast). Symbolically, the exponentially smoothed forecast is given by

$${}_{(1s)}\hat{X}_t = \alpha X_t + (1-\alpha) {}_{(1s)}\hat{X}_{t-1}$$

where

${}_{(1s)}\hat{X}_t$ = the new forecast for the t^{th} time point, and (1s) indicates this is the result of single exponential smoothing

${}_{(1s)}\hat{X}_{t-1}$ = the old forecast for the $t^{th}-1$ time point

X_t = the observed demand for the t^{th} time point.

α = the smoothing constant (alpha).

Using the demand from table 7, a smoothing constant of $\alpha=0.1$ and an initial estimate $\hat{X}_8=17.1$ obtained from table 8 (using the moving average technique), the exponentially smoothed forecast for $t=9$ becomes

$$\hat{X}_9 = (0.1)(24) + (0.9)(17.1) = 17.8.$$

This forecast, \hat{X}_9 , is an estimate of future demand. The actual demand for $t=10$ was 29 units, so that our forecast represented an underestimate of the demand one time period in the future. A more

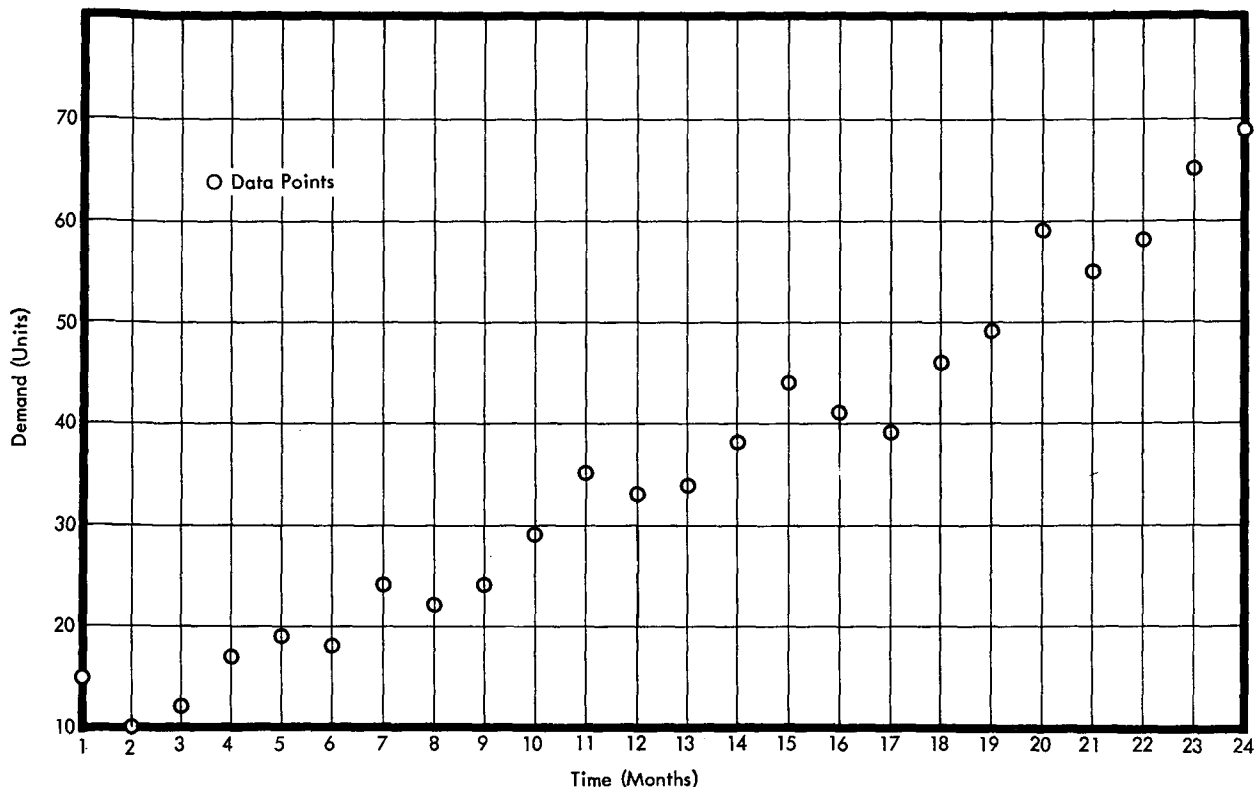


Figure 14. Monthly demand data recorded over a 2-year period.

detailed investigation of the data being considered would indicate that the basic model was not constant but linear, and a more sophisticated approach like double moving averages would be preferable (para 58-60).

b. This method tends to give an overall average based on all previous demands while continually adjusting for errors in the forecasting process. A graphical presentation of the two smoothing techniques discussed so far is presented in figure 15.

c. The relationship between the process of exponential smoothing and the contribution made by the "older" data for a smoothing constant of 0.5 (i.e., $\alpha=0.5$) is presented in figure 16. Note that over 98 percent of the weight is given to the last five demand records and that the forecast gives less than two percent weight to demands more than five time periods distant.

Table 9 shows the relationship between the smoothing constant α and the maximum number of time periods that contribute significantly to a forecast.

It is apparent that small values of the smoothing constant α are best when the average demand remains essentially constant; but when data are changing radically, a larger value of α would be more appropriate.

d. For comparison purposes, the same data used in the moving average example of the preceding paragraphs will be analyzed by exponential smoothing techniques. A value of $\alpha=0.1$ was initially selected for the smoothing constant. The calculation procedure and numerical results are presented in table 10, while the graphical results were shown earlier in figure 15. Notice the tendency for the forecast to lag behind the observed demand pattern. This is due to the fact that the data has a noticeable trend and the exponentially smoothed forecast as used does not adjust for trend. Smoothing of data with a secular trend is covered in paragraphs 58 through 60.

56. Selection of a Smoothing Constant

a. How much historical data are needed to provide a good estimate? By a good estimate is

Table 8. Moving Averages for Total Demand Data

Date	Data	Moving Average Forecast	Date	Data	Moving Average Forecast
t	X_t	$\bar{X} (N=8)$	t	X_t	$\bar{X} (N=8)$
1	15		13	34	27.4
2	10		14	38	29.9
3	12		15	44	32.4
4	17		16	41	34.8
5	19		17	39	36.6
6	18		18	46	38.8
7	24		19	49	40.5
8	22	17.1(A)	20	59	43.8
9	24	18.2(B)	21	55	46.4
10	29	20.6	22	58	48.9
11	35	23.5	23	65	51.5
12	33	25.5	24	69	55.0

Data: Item demand over 24 months

Model: Constant $X_t = a + E_t$

Smoothing: Moving Average, $N = 8$

$$\bar{X} = \frac{X_t + X_{t-1} + \dots + X_{t-N+1}}{N}$$

(A): $\bar{X} = \frac{22 + 24 + 18 + 19 + 17 + 12 + 10 + 15}{8} = 17.1$

(B): $\bar{X} = \frac{24 + 22 + 24 + 18 + 19 + 17 + 12 + 10}{8} = 18.2$

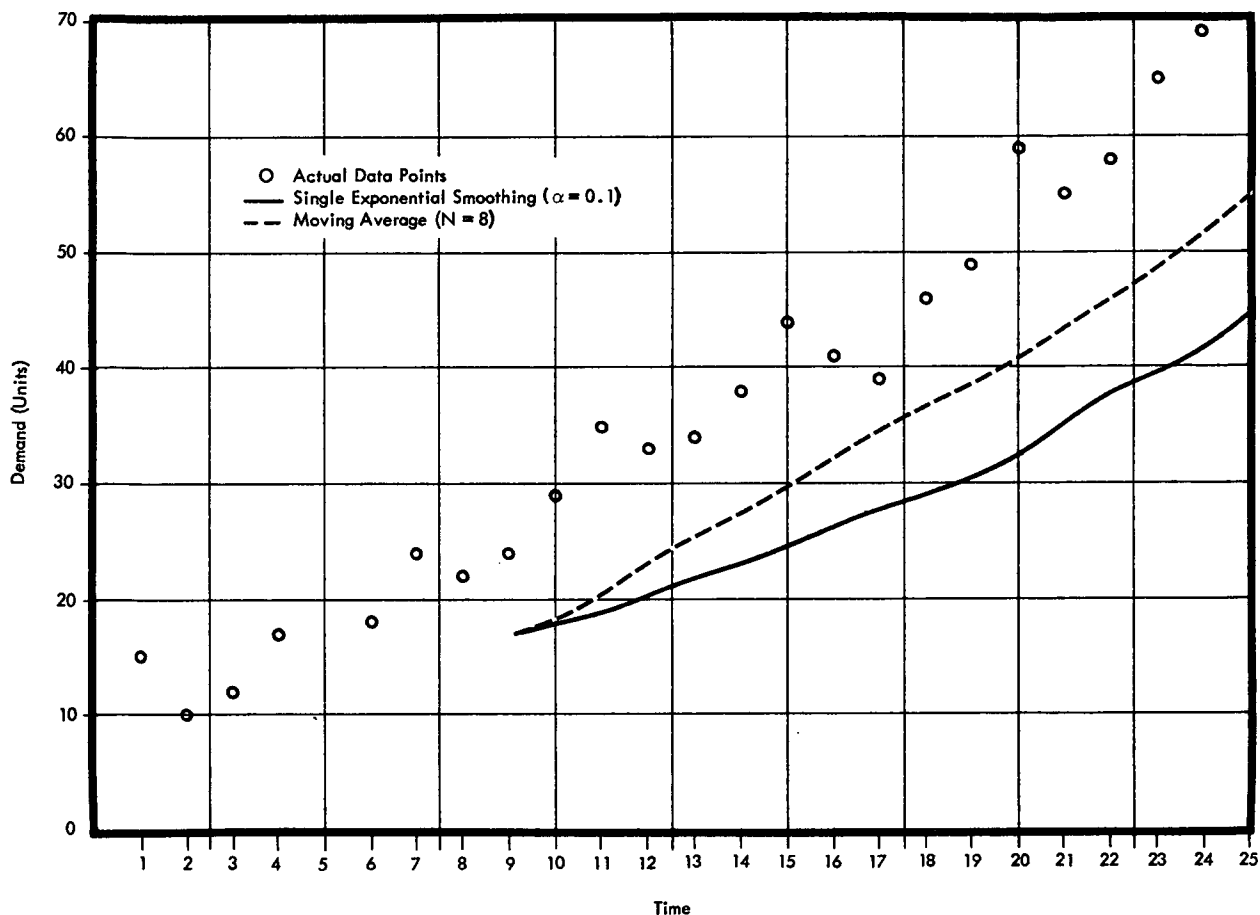


Figure 15. Comparison of single smoothing and moving average techniques (demand vs time).

meant a forecast that is not affected excessively by random fluctuations and yet reacts quickly to real changes in the average demand level. An optimum value of α can be derived by examining a variety of values of α in light of this forecast error.

b. One technique is to use a quantity called the Mean Absolute Deviation (*MAD*), that is,

$$MAD = \alpha |X_{t-(1s)} \hat{X}_{t-1}| + (1 - \alpha) MAD_{t-1}$$

where

$(1s) \hat{X}_{t-1}$ = the forecasted demand at time $t-1$

X_t = the actual observed demand at time t

MAD_{t-1} = mean absolute deviation calculated at $t-1$

Note. The vertical lines in the above formula indicate the sign of the difference of $X_{t-(1s)} \hat{X}_{t-1}$ is disregarded.

The values of the *MAD* are plotted against α , and the minimum value is defined to be the "best" smoothing constant. Based on available information, an α in the neighborhood of 0.1 has the widest range of application. However, as the example presented in this chapter illustrates, forecasts based on $\alpha = 0.1$ may not always produce a satisfactory result. When this happens, the data should be examined to see if a trend correction is required or perhaps a higher value of α should be used for a few periods to adjust for temporary variations in the data.

c. In order to initiate the use of an exponential smoothing application in a forecasting situation, some beginning forecast is required. One method is to choose an initial forecast based on a moving average technique. An alternative procedure is to use the first demand record as the starting point. As the process is carried out over an extended period of time, the significance of the initial estimate becomes less and less important.

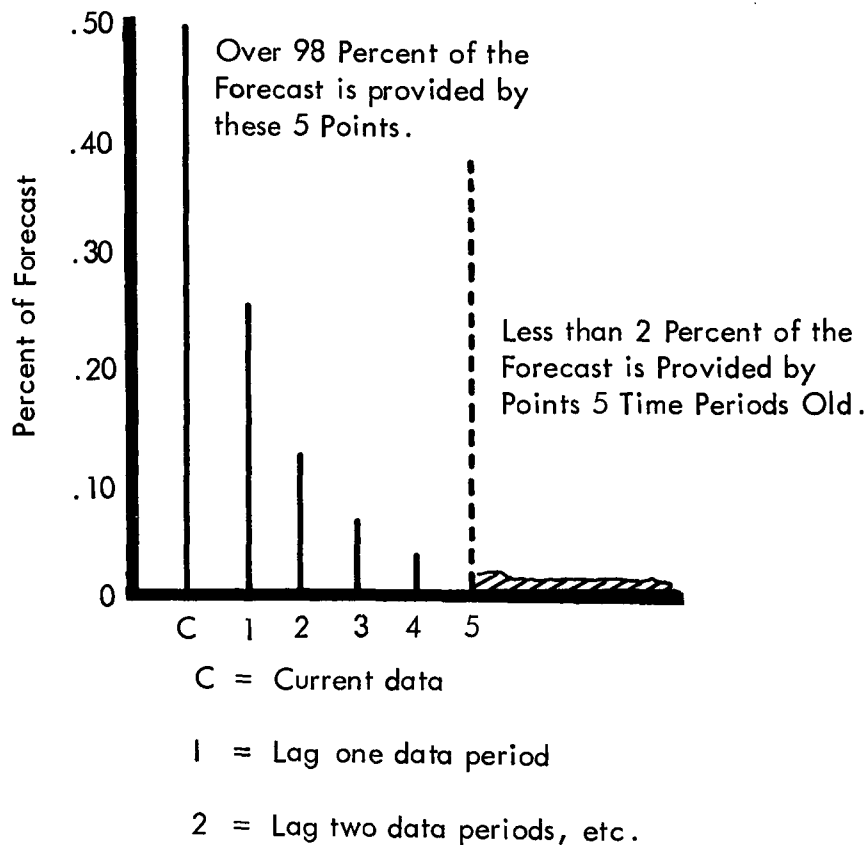


Figure 16. The effect of a smoothing constant on "old" data.

Table 9. The Relationship Between the Smoothing Constant and the Number of "old" Data Points that Contribute to a Forecast

Smoothing Constant	Maximum Number of Time Units That Contribute Significantly to the Forecast
.01	199
.10	19
.20	9
.50	3

Table 10. Exponential Smoothing for Total Demand Data

Date	Data	Smoothed Forecast	Date	Data	Smoothed Forecast
t	X_t	$\hat{X}_{(s)t}$	t	X_t	$\hat{X}_{(s)t}$
1	15		13	34	23.0
2	10		14	38	24.5
3	12		15	44	26.4
4	17		16	41	27.9
5	19		17	39	29.0
6	18		18	46	30.7
7	24		19	49	32.5
8	22	17.1	20	59	35.2
9	24	17.8(A)	21	55	37.2
10	29	18.9(B)	22	58	39.3
11	35	20.5	23	65	41.9
12	33	21.8	24	69	44.6

Data: Item demands over 24 months

Model: Constant $X_t = a + E_t$

Smoothing: Exponential Smoothing: $\alpha = 0.1$

$$\hat{X}_{(s)8} = 17.1$$

$$\hat{X}_{(s)t} = 0.1 X_t + 0.9 \left[\hat{X}_{(s)t-1} \right]$$

$$(A): \hat{X}_{(s)9} = (0.1)(24) + (0.9)(17.1) = 17.8$$

$$(B): \hat{X}_{(s)10} = (0.1)(29) + (0.9)(17.8) = 18.9$$

57. Demand Filtering (Outliers)

a. The demand filtering technique can be used to improve accuracy of forecasts by eliminating widely varying data points suspected of being unrepresentative or incorrect. The procedure consists of determining the expected demand for a period and setting confidence limits about this expected demand. A set of upper and lower control levels are established. An item is accepted if it falls between these levels but is rejected if it falls outside the tolerance zone.

b. For example, if the demand data were normally distributed with an average (μ) equal to 100 items and a standard deviation (σ) of 20 items, the upper control limit could be

$$100 + 2(20) = 140$$

and the lower control limit could be

$$100 - 2(20) = 60$$

Section IV. SMOOTHING TECHNIQUES FOR SECULAR TRENDS

58. A Second Model

a. Assume that an examination of demand data for a secondary item suggests a changing demand pattern, as in the illustrative example. Inspection of the data plotted on figure 14 reveals that the demand pattern appears to be changing at a constant rate. This type of demand pattern is exhibiting a linear trend which can be expressed mathematically as

$$X_t + T = a_t + b_t T + E_t$$

where

X_t = the observed demand at time t

a_t = the initial demand at $T=0$

b_t = the constant rate of change

T = the time over which the forecast is being made

E_t = the error due to random fluctuation at time t .

b. A linear model of this type is useful whenever linear trends exist in the demand data. However, applying this model and investigating the nature of the trend in a real situation require a forecasting technique that provides estimates of both a_t and b_t . Two such numerical procedures will be considered in this section—the least squares and

By using 60 and 140 as control limits, any observation greater than 140 or less than 60 would be filtered out as being unrepresentative of the demand pattern.

c. Since 95.44 percent of the area under the normal curve lies between $\mu \pm 2\sigma$ (ch 9 and 16), this implies that 46 demands out of 1000 $((1 - 0.9544)1000 = 45.6)$ would be expected to fall outside the filter limits. If, after many demands had been recorded, significantly more than 4.56 percent of the demands exceeded 140 or were less than 60, it would be a warning to the analyst that the demand pattern is not remaining constant. He should then investigate the item in sufficient detail to determine the underlying reason(s) for the changing demand pattern. Conversion of *MAD* to standard deviation is discussed in chapter 9.

d. The use of statistical control charts in regard to analysis of demand distributions is discussed in chapter 16.

double exponential smoothing methods. The least squares technique has a variety of applications outside the area of demand forecasting and will be introduced first.

59. Method of Least Squares

a. Briefly stated, the method of least squares is a technique designed to estimate both the beginning demand level a_t and the constant rate of change b_t . These two quantities are estimated by fitting the model to the observed demand data in a special way. The process consists of choosing a_t and b_t so that the errors caused by fitting the demand data are as small as possible. A graphical illustration of the least squares is given in figure 17.

Note that the method consists of making the differences between the observed demands and the fitted line as small as possible. Also, \hat{a}_t is the demand at the start of the forecasting process, $T=0$, and \hat{b}_t is the constant rate of increase (or slope of the fitted line). Mathematically, this is accomplished by defining a quantity

$$\phi = \sum (\hat{a}_t + \hat{b}_t T - X_{t+T})^2$$

where ϕ is the squared deviation of the fitted data ($\hat{a}_t + \hat{b}_t T$) from the observed demand (X_{t+T})

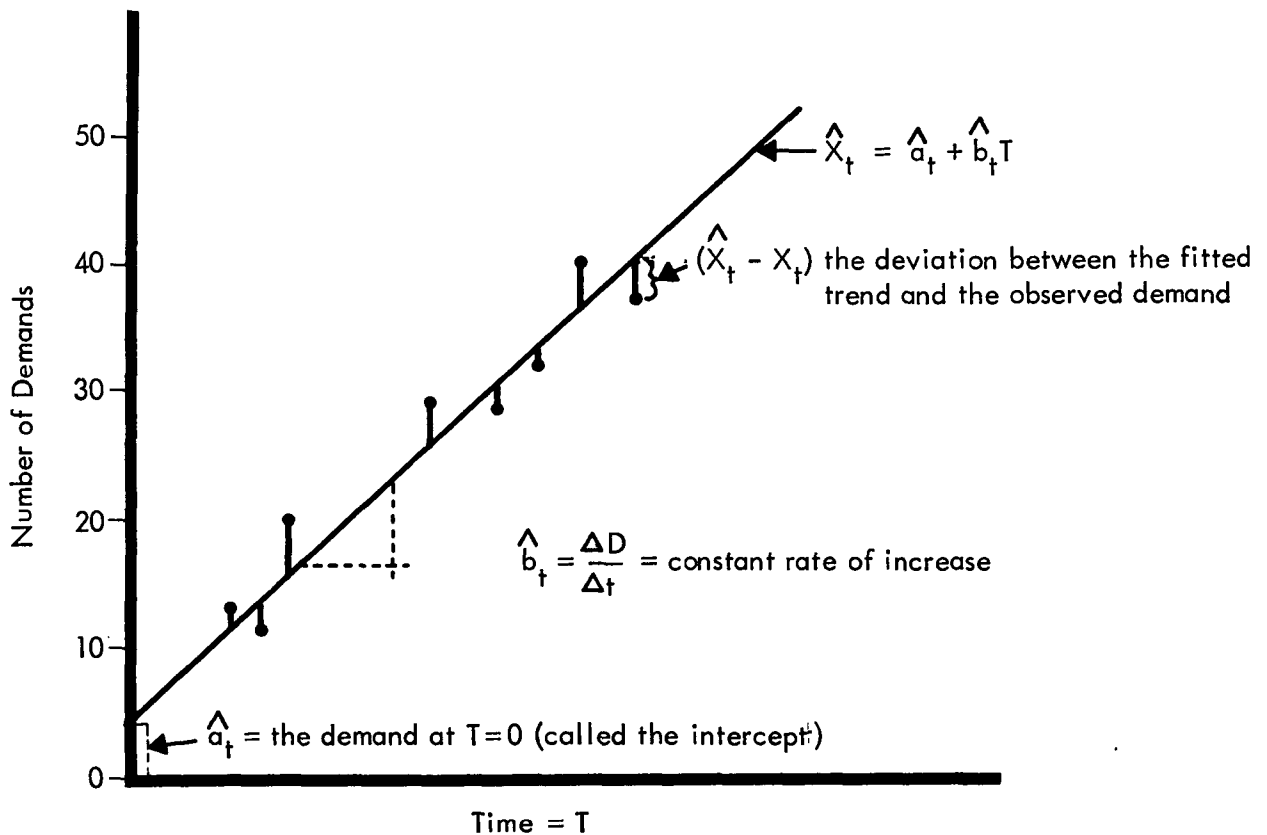


Figure 17. The method of least squares (is to minimize $(\hat{X}_t - X_t)$).

at time $t+T$. The symbol Σ , sigma, indicates that the sum is taken over all demand records.

b. The process of choosing the best \hat{a}_t and \hat{b}_t , mathematically, is a minimization technique. The derivative of ϕ is obtained with respect to \hat{a}_t and \hat{b}_t , and the two resulting equations are set equal to zero. The "best" values of the initial demand (\hat{a}_t) and the rate of change (\hat{b}_t) are obtained by the simultaneous solution of the two resulting equations.

c. In the special case where a moving average is the basic technique of interest, it is possible to select a new time scale, namely, $t' = t - (N-1)/2$, where N is the number of terms used in the averaging process. When this transformation of the time periods has been made, the least squares technique leads to estimates of \hat{a}_t and \hat{b}_t in terms of the moving averages. More specifically,

$$\hat{a}_t = 2\hat{X}_t - {}_{(2)}\hat{X}_t$$

where

\hat{X}_t = the moving average obtained from the original demand data

${}_{(2)}\hat{X}_t$ = a moving average obtained by using the first set of moving averages in place of the original demand data. This is called a double moving average;

and

$$\hat{b}_t = \frac{2}{N-1}(\hat{X}_t - {}_{(2)}\hat{X}_t)$$

where N is the number of moving averages used in computing \hat{X}_t and ${}_{(2)}\hat{X}_t$, the first and second moving averages.

d. With the estimates of a_t and b_t obtained by the double moving average technique, the forecast for the next time period (t) is given by

$${}_{(2)}\hat{X}_{t+1} = \hat{a}_t + \hat{b}_t$$

(The presubscript (2) indicates that a double moving average was employed.) If, on the other

hand, the forecast is to apply to some T time units from t (the current time point), it can be written

$${}_{(2)}\hat{X}_{t+T} = \hat{a}_t + \hat{b}_t T$$

where T is the length of time over which the forecast is to be made.

e. When the data contain an inherent seasonal pattern, the technique of using a linear model can be used to smooth out the effect of seasonality. This is accomplished by letting $N = 12$ months.

f. The method of least squares will now be applied to the data originally presented in table 7. The calculations are contained in table 11, and the forecasted demands are contrasted with those actually observed in figure 18. Although the fit is not appreciably better than the single smoothed curve, this method does at least enable one to compute the rate of change of the demand pattern. In table 11, \hat{b}_t is estimated as an increase of about 2.5 demands per month.

60. Method of Double Exponential Smoothing

a. Another technique for arithmetically generating a forecast is that of double exponential smoothing. This procedure carries the method of exponential smoothing on to a second stage. As in the case of moving averages resulting from the least squares approach, the second smoothing is carried out on the data generated from single exponential smoothing. Thus, double smoothed results are obtained directly from the single smoothed data by repeating the process on the latter.

b. The results of both smoothing processes are combined to obtain estimates of the initial demand \hat{a}_t and the constant rate of change \hat{b}_t . The estimates of these two quantities are:

$$\hat{a}_t = 2{}_{(1s)}\hat{X}_t - {}_{(2s)}\hat{X}_t$$

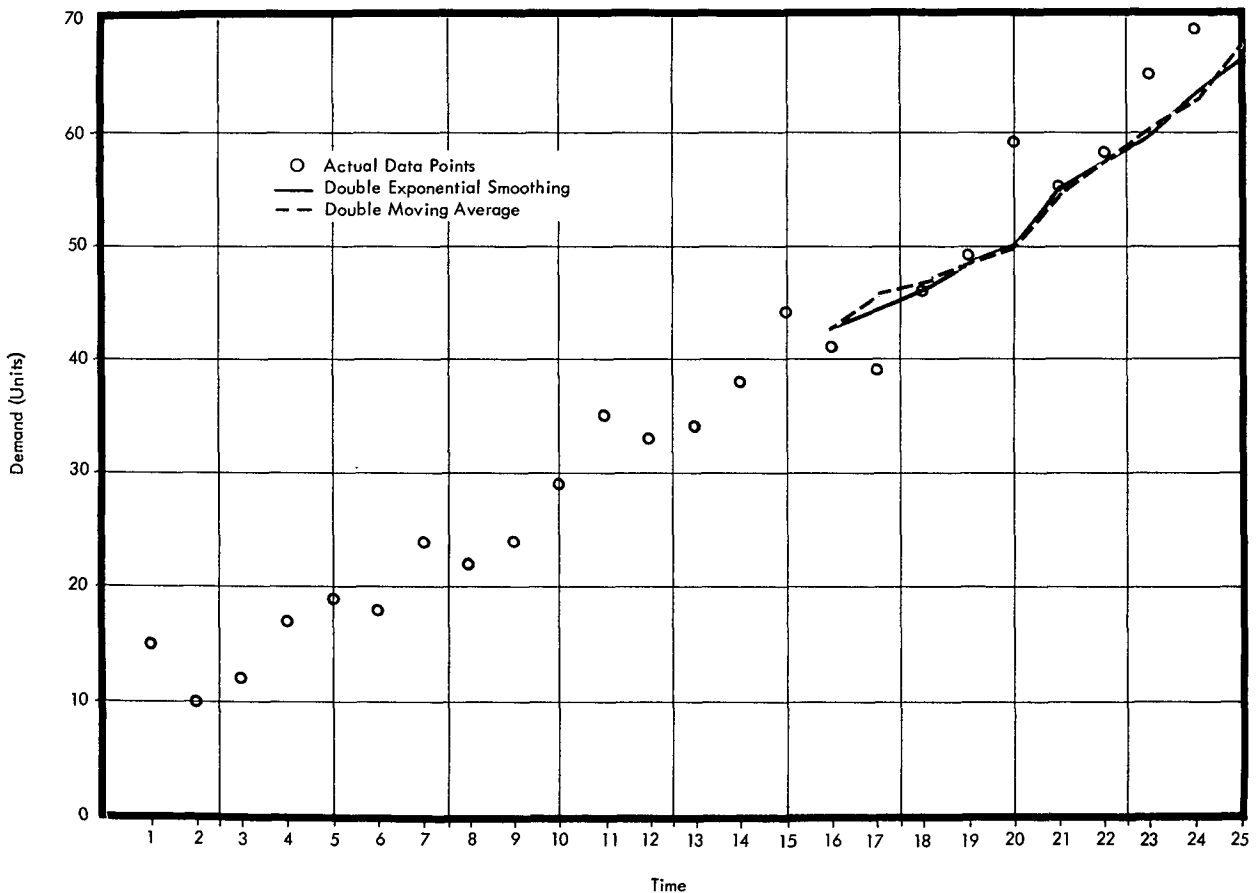


Figure 18. Comparison of double smoothing techniques (demand vs time).

Table 11. Manual Least Squares Computations Based on Double Moving Averages

Date t	Data X_t	Moving Average X_t	Double Average $(2)X_t$	Coefficients		Forecast \hat{X}_t
				\hat{a}_t	\hat{b}_t	
1	15					
2	10					
3	12					
4	17					
5	19					
6	18					
7	24					
8	22	17.1				
9	24	18.2				
10	29	20.6				
11	35	23.5				
12	33	25.5				
13	34	27.4				
14	38	29.9				
15	44	32.4	24.3	40.5	2.3	42.8(A)
16	41	34.8	26.5	43.1	2.4	45.5(B)
17	39	36.6	28.8	44.4	2.2	46.6
18	46	38.8	31.1	46.5	2.2	48.7
19	49	40.5	33.2	47.8	2.1	49.9
20	59	43.8	35.5	52.1	2.4	54.5
21	55	46.4	37.9	54.9	2.4	57.3
22	58	48.9	40.2	57.5	2.5	60.0
23	65	51.5	42.7	60.3	2.5	62.8
24	69	55.0	45.2	64.8	2.8	67.6

(A): $(2)X_{15} = \frac{32.4 + 29.9 + \dots + 17.1}{8} = 24.3$

$\hat{a}_{15} = 2(32.4) - 24.3 = 40.5$

$\hat{b}_{15} = \frac{2}{7} (32.4 - 24.3) = 2.3$

$\hat{X}_{16} = 40.5 + 2.3 = 42.8$

Data: Item demands over 24 months

Model: Linear $X_t = a + bt + E_t$

Smoothing: Double Moving Average, $N = 8$

Forecast: $\hat{X}_t = \hat{a}_t + \hat{b}_t$

$$X_t = \frac{X_t + X_{t-1} + \dots + X_{t-N+1}}{N}$$

$$(2)X_t = \frac{\hat{X}_t + \hat{X}_{t-1} + \dots + \hat{X}_{t-N+1}}{N}$$

$$\hat{a}_t = 2X_t - (2)X_t$$

$$\hat{b}_t = \frac{2}{N-1} (X_t - (2)X_t)$$

(B): $(2)X_{16} = \frac{34.8 + 32.4 + \dots + 18.2}{8} = 26.5$

$\hat{a}_{16} = 2(34.8) - 26.5 = 43.1$

$\hat{b}_{16} = \frac{2}{7} (34.8 - 26.5) = 2.4$

$\hat{X}_{17} = 43.1 + 2.4 = 45.5$

where the presubscript (1s) indicates single smoothing, and (2s) indicates double exponential smoothing.

${}_{(1s)}\hat{X}_t$ = the estimated demand for time period t using single smoothing

${}_{(2s)}\hat{X}_t$ = the result of smoothing the quantities ${}_{(1s)}\hat{X}_t$, thus double exponential smoothing

and b_t , the estimated rate of change, is

$$\hat{b}_t = \left(\frac{\alpha}{1-\alpha} \right) ({}_{(1s)}\hat{X}_t - {}_{(2s)}\hat{X}_t)$$

where α is the smoothing constant used in both processes of exponential smoothing.

c. Once the initial estimates have been supplied, the process of double exponential smoothing is easy to use. To get the process started, estimates of two initial smoothed values are required, denoted ${}_{(1s)}\hat{X}_0$ and ${}_{(2s)}\hat{X}_0$, respectively. ${}_{(1s)}\hat{X}_0$ is the initial estimate for single exponential smoothing, and ${}_{(2s)}\hat{X}_0$ is the initial estimate for double exponential smoothed demands. One method of

estimating these initial values is to estimate a_t and b_t by the method of least squares and then compute

$${}_{(1s)}\hat{X}_0 = \hat{a}_0 - \frac{(1-\alpha)}{\alpha} \hat{b}_0$$

and

$${}_{(2s)}\hat{X}_0 = \hat{a}_0 - 2 \frac{(1-\alpha)}{\alpha} \hat{b}_0$$

A numerical illustration of this computation is presented in table 12.

d. If past data are not available, it may be possible to apply the estimates of \hat{a}_t and \hat{b}_t being used on a similar stocked item as a means of starting the process.

e. An example of how to carry through the arithmetic details of exponential smoothing is given below using the demand data of table 7. A second smoothing constant of 0.1 is used, and the numerical values corresponding to the least square estimates of \hat{a} and \hat{b} for $t=15$ (table 10) are used to begin the process. The forecasts were presented graphically in figure 18.

Table 12. Double Exponential Smoothing

Date t	Data X_t	Smoothed Data ${}_{(1s)}\hat{X}_t$	Double Smoothed Data ${}_{(2s)}\hat{X}_t$	Coefficients		Forecast \hat{X}_t
				\hat{a}_t	\hat{b}_t	
1	15					
2	10					
3	12					
4	17					
5	19					
6	18					
7	24					
8	22					
9	24					
10	29					
11	35					
12	33					
13	34					
14	38					
15	44	19.8	-0.9	40.5*	2.3**	
16	41	21.9	1.4	42.4	2.3	44.7(A)
17	39	23.6	3.4	43.8	2.2	46.0
18	46	25.8	5.4	46.2	2.3	48.5
19	49	28.1	7.7	48.5	2.3	50.8
20	59	31.2	10.0	52.4	2.4	54.8
21	55	33.6	12.4	54.8	2.4	57.2
22	58	36.0	14.8	57.2	2.4	59.6
23	65	38.9	17.2	60.6	2.4	63.0
24	69	41.9	19.7	64.1	2.5	66.6

(A): ${}_{(s)}\hat{X}_{16} = .1(41) + .9(19.8) = 21.9$
 ${}_{(2s)}\hat{X}_{16} = .1(21.9) + .9(-0.9) = 1.4$
 $\hat{a}_{16} = 2(21.9) - 1.4 = 42.4$
 $\hat{b}_{16} = \frac{0.1}{0.9}(21.9 - 1.4) = 2.3$

Data: Item demands over 24 months
Model: Linear $X_t = a + bt$
Smoothing: Double Exponential Smoothing: $\alpha = 0.1$

$${}_{(1s)}\hat{X}_t = \alpha X_t + (1 - \alpha){}_{(1s)}\hat{X}_{t-1}$$

$${}_{(2s)}\hat{X}_t = \alpha {}_{(1s)}\hat{X}_t + (1 - \alpha){}_{(2s)}\hat{X}_{t-1}$$

$$\hat{a}_t = 2 {}_{(s)}\hat{X}_t - {}_{(2s)}\hat{X}_t$$

$$\hat{b}_t = \frac{0.1}{0.9} ({}_{(s)}\hat{X}_t - {}_{(2s)}\hat{X}_t)$$

Forecast: $\hat{X}_t = \hat{a}_t + \hat{b}_t$

Calculation of Initial Values:

$${}_{(s)}\hat{X}_0 = \hat{a}_0 - \frac{1-\alpha}{\alpha} \hat{b}_0 = 40.5 - \left(\frac{.9}{.1}\right)(2.3) = 40.5 - 20.7 = 19.8$$

$${}_{(2s)}\hat{X}_0 = \hat{a}_0 - 2\left(\frac{1-\alpha}{\alpha}\right) \hat{b}_0 = 40.5 - 2\left(\frac{.9}{.1}\right)(2.3) = -0.9$$

* $\hat{a}_0 = \hat{a}_{15}$, Table 11 = 40.5
** $\hat{b}_0 = \hat{b}_{15}$, Table 11 = 2.3

CHAPTER 6

STRATIFICATION OF REQUIREMENTS

Section I. GENERAL

61. Introduction

a. AR 320-5 defines *requirements* as, "a plan or statement indicating the need or demand for personnel, equipment, supplies, resources, facilities, or services by specific quantities for specific periods of time or at specific times." The key words in this definition are *need* and *time*.

b. Requirements, as a need in the logistics context, are normally described as a quantity of materiel. Physical stocks of equipment or supplies, whether in inventory or in the hands of troops, represent whole or partial fulfillment of a requirement. It is also apparent that this physical and quantitative need has the further dimension of location.

c. Requirements, however, is a meaningless term unless the quantity and location needs are further defined by an additional element, time. In some cases it may be desirable to describe the time dimension of a requirement as a single date: x units of an item delivered to location y by date z . More often the time element covers a period with an identifiable beginning and ending—a monthly, a fiscal year, a procurement lead time period, etc.

d. In brief, a requirement can be stipulated by answering four questions about an item of equipment or supply:

- (1) *How much* is needed?
- (2) *Where* is it needed?
- (3) *When* is the first delivery required?
- (4) *At what rate* will the item be used?

e. It is apparent from the introductory statements above that requirements for a particular stocked item will be different at different levels of the supply system. Quantitative requirements are a function of the number of

consumers supported, the mission of the stocking agency, and the control system (i.e., inventory model) used. Also, it should be noted that requirements for repairable items are determined on a different basis than for nonrepairables. Indeed, special terms are used in describing repairable requirements to express clearly the necessary distinctions. Therefore, in order to simplify the discussion of requirements, the first three sections of this chapter are limited in scope to requirements for nonrepairables at the NICP level. Requirement determination at the oversea ICP level is treated separately in paragraphs 75 through 77. Chapter 11 is devoted to the subject of repairables and includes some discussion of requirements.

62. Relationship to Inventories

a. Materiel requirements are met through the acquisition, storage, and distribution of appropriate equipments and supplies. Assuming proper balance among stockage points, the degree to which a requirement is satisfied can be determined by comparing the quantitative requirement with available assets (stocks on order, in storage, or in hands of troops) across time. It should be borne in mind, however, that inventories are a physical fact at a point in time, whereas requirements are less tangible—an objective or plan which embodies a time dimension.

b. Requirements for secondary items are dynamic in nature in that they change from period to period as new end items are introduced into the system, increase in distribution densities, age and require replacement, and eventually are withdrawn from use. In another sense, however, requirements may be treated

as static. When a supply control study is made at a given point in time and with specified conditions, a particular quantitative requirement can be calculated to cover the period from time now to some selected date at a given number of months in the future. Requirements are treated as static when a procurement quantity is calculated and a single order placed. However, it is important that the dynamic character of requirements be kept in mind. One reason for the use of review cycles and reorder points is to insure that changes in requirements are promptly identified.

63. Stratification of Requirements

a. "Stratify" means to form or arrange in layers. Requirements, as well as inventories, are stratified into increments in order to facili-

tate analysis and to insure that all factors receive appropriate consideration.

b. The layering of requirements can best be illustrated by the use of a bar chart as shown in figure 19. In this diagram the principal stratifications of requirements presently used in the Army have been shown in approximate order of priority from bottom to top. The reasons for the selection of these stratifications, the scientific inventory control basis for the quantities represented by specific layers, and the interrelationships among stratifications are discussed in paragraphs 64 through 77:

c. For certain budget derivation and reporting purposes, it is necessary to further stratify requirements and assets into the balance of the current year, apportionment year, and

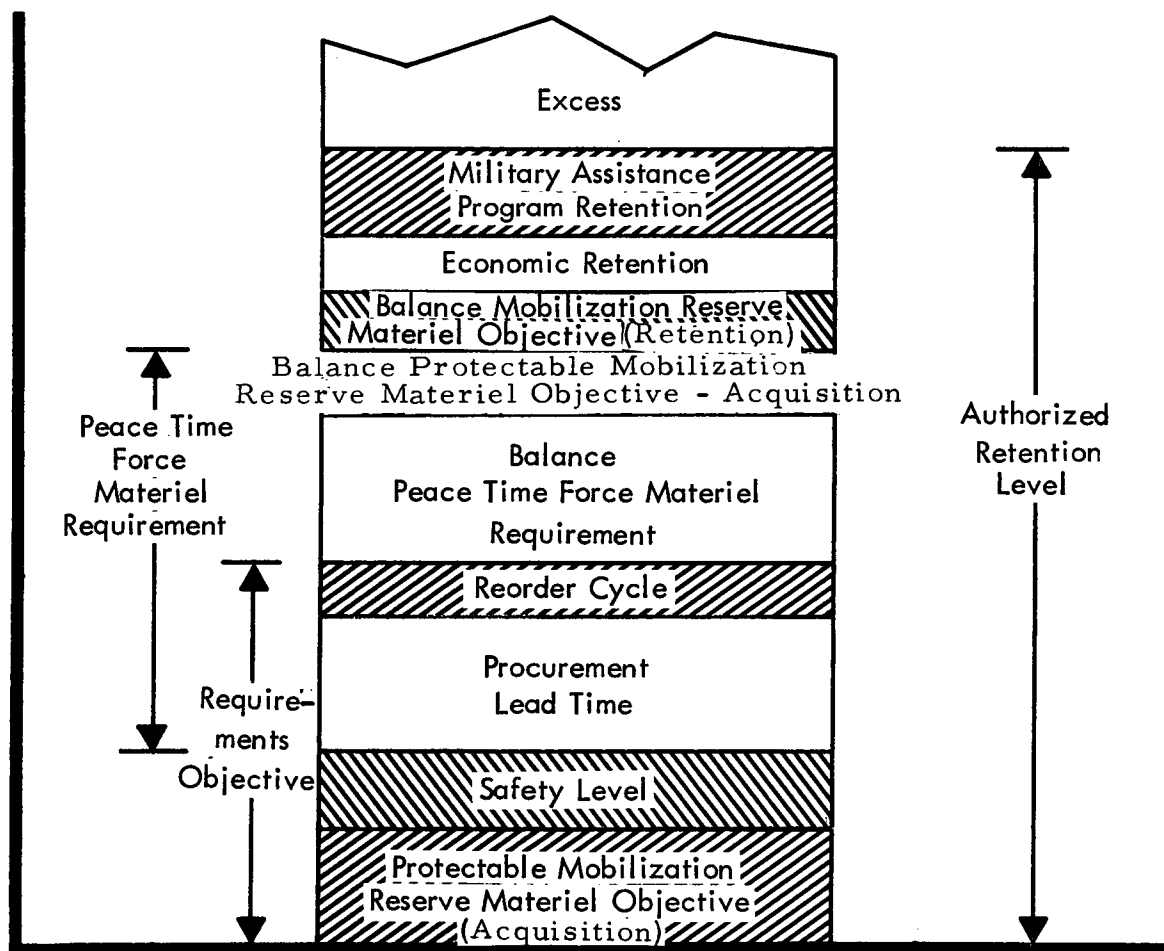


Figure 19. Stratification of requirements.

budget year segments. As these stratifications are primarily of interest for reasons of finan-

cial control instead of supply control, they are not discussed in this manual.

Section II. THE REQUIREMENTS OBJECTIVE

64. Definitions

a. There are four important stratifications in the requirements objective—reorder cycle; procurement lead time quantity; safety level; and protectable mobilization reserve materiel objective. The following definitions, contained in part in AR 320-5 and AR 710-45, are repeated here to insure an appropriate frame of reference. These stratifications are further defined with illustrative examples in the remaining paragraph of this section.

(1) *Requirements Objective (RO)*. "The maximum quantity of materiel to be maintained on hand and on order, at any one time, to sustain current operations and objectives. It consists of the sum of requirement represented by the reorder cycle quantity, the procurement lead time quantity, safety level quantity and protectable mobilization reserve materiel objectives or emergency level of supply, and prepositioned war reserve requirements, as appropriate (AR 320-5)." The RO is derived by summing its constituent parts, and it is used in control schemes as a maximum quantity. It can also be described as: Reorder cycle + procurement lead time + prepositioned war reserve requirements.

(2) *Reorder Cycle (REOCY)*. "The interval between successive reorder (procurement) actions." (AR 320-5 and AR 710-54.) The quantity of an item associated with the reorder cycle is called the reorder cycle quantity. It is equivalent to the product of the reorder cycle (in months) and the forecasted average monthly demand. The reorder cycle should not be confused with the review cycle. The reorder cycle is determined through a cost analysis that generally hinges on the calculation of an economic

order quantity. On the other hand, the review cycle is established on the basis of the item's critically or annual dollar demand to insure that forecasts are checked on a frequency commensurate with the item's importance.

(3) *Procurement Lead Time (PROLT)*. "The time interval from the date of the supply control study resulting in procurement action to the receipt of the first shipment in the supply system. It is composed of the following elements: administrative lead time, production lead time, and delivery lead time." (AR 710-45.) The procurement lead time quantity, used in forecasting requirements, is equal to the product of the PROLT (in months) and the forecasted average monthly demand.

(4) *Safety Level (SL)*. "The quantity of materiel (in addition to operating stocks) required to permit continued operations in event of variation above the mean averages of lead times or demands. The type of safety levels are—

(a) *Fixed Safety Level (FSL)*. A quantity of stock to be on hand to provide a degree of protection against stockout for each item. The quantity is equal to expected demand over a fixed number of days. A fixed safety level of 30 days usage will not provide a uniform level of protection to individual stock items because of differences in variability of demand.

(b) *Variable Safety Level (VSL)*. A quantity of stock to be on hand to provide a predetermined degree of protection against stockouts for each item. The level is based on probability principles and a realis-

tic appraisal of the frequency of demands, reorder frequency, average order size, length of lead time, variability of lead time, and delivery schedule." (AR 710-45.)

- (5) *Protectable Mobilization Reserve Materiel Objective (PMRMO)*. "That portion of the total mobilization reserve materiel objective (MRMO) representing the quantity of an item planned to be held in mobilization reserve inventories and procured for such inventories within the fund limitations of the current fiscal year." (AR 710-45.)
- (6) *Emergency Level (EL)*. "A level of supply established for certain mobilization reserve items. This level is authorized in lieu of general mobilization reserve materiel requirement and the peacetime safety level for those items where the economic order principles are applied and results in an operating level of supply of two years or more." (AR 710-45.)
- (7) *Preposition War Reserve Requirement (PPWRR)*. "That portion of the MRMO that strategic plans dictate be positioned prior to hostilities at or near the point of planned use or issue to the user, to insure timely support of a specific project or designated force during the initial plan of war, pending arrival of replenishment shipments." (AR 320-5.)

b. An inventory stratification that, while not strictly a part of the RO, influences procurement quantities directly is the quantity of dues-out or back orders. Dues-out represent an obligation to issue materiel as soon as replenishment stocks are received. In this sense they can be treated as a negative inventory and must be reflected in any comparison of RO with stock on hand and on order.

65. The Protectable Mobilization Reserve Materiel Objective (PMRMO)

a. The PMRMO includes not only those mobilization reserve quantities on hand at the time of a supply control study, but also addi-

tional mobilization procurements planned in the current fiscal year.

b. Except in those few instances where mobilization reserves are prepositioned for strategic reasons, and administratively earmarked in a separate account code, it is generally impossible to identify a specific lot of end items or repair parts as a physical portion of the PMRMO stratification. In actual practice assets theoretically carried as PMRMO are often issued when an item is in short supply throughout the depot system. Stocks so issued should be replaced immediately with peacetime funds in order to protect the mobilization investment from depletion for peacetime use. While it is the intent of regulations and directives that PMRMO stocks be reserved for mobilization purposes, the current situation often makes it virtually impossible to do so.

c. In summary, while it is appropriate that PMRMO be considered a primary and inviolable requirements stratification, it should also be borne in mind that the limitations of the present supply system make it difficult to achieve these objectives. Further, when budgetary constraints are superimposed on these system shortcomings, constant maintenance of PMRMO as on hand stocks is impracticable. In these instances, NICP's should summarize the value of mobilization stocks not replaced and justify this action in the next budget presentation.

66. Variable and Fixed Safety Levels

a. Safety levels are included in requirements stratifications to provide protection against stockouts. Fixed safety levels are determined arbitrarily, whereas variable safety levels are based on probability principles and on analysis of historical data. The following paragraphs provide an introduction to the need for and determination of safety levels. A more comprehensive treatment of the variable safety level is contained in chapter 9.

b. As an illustration of a simple supply control problem, consider the following situation. The housewife who feeds her pet one can of cat food per day and markets every Tuesday has a simple requirements problem.

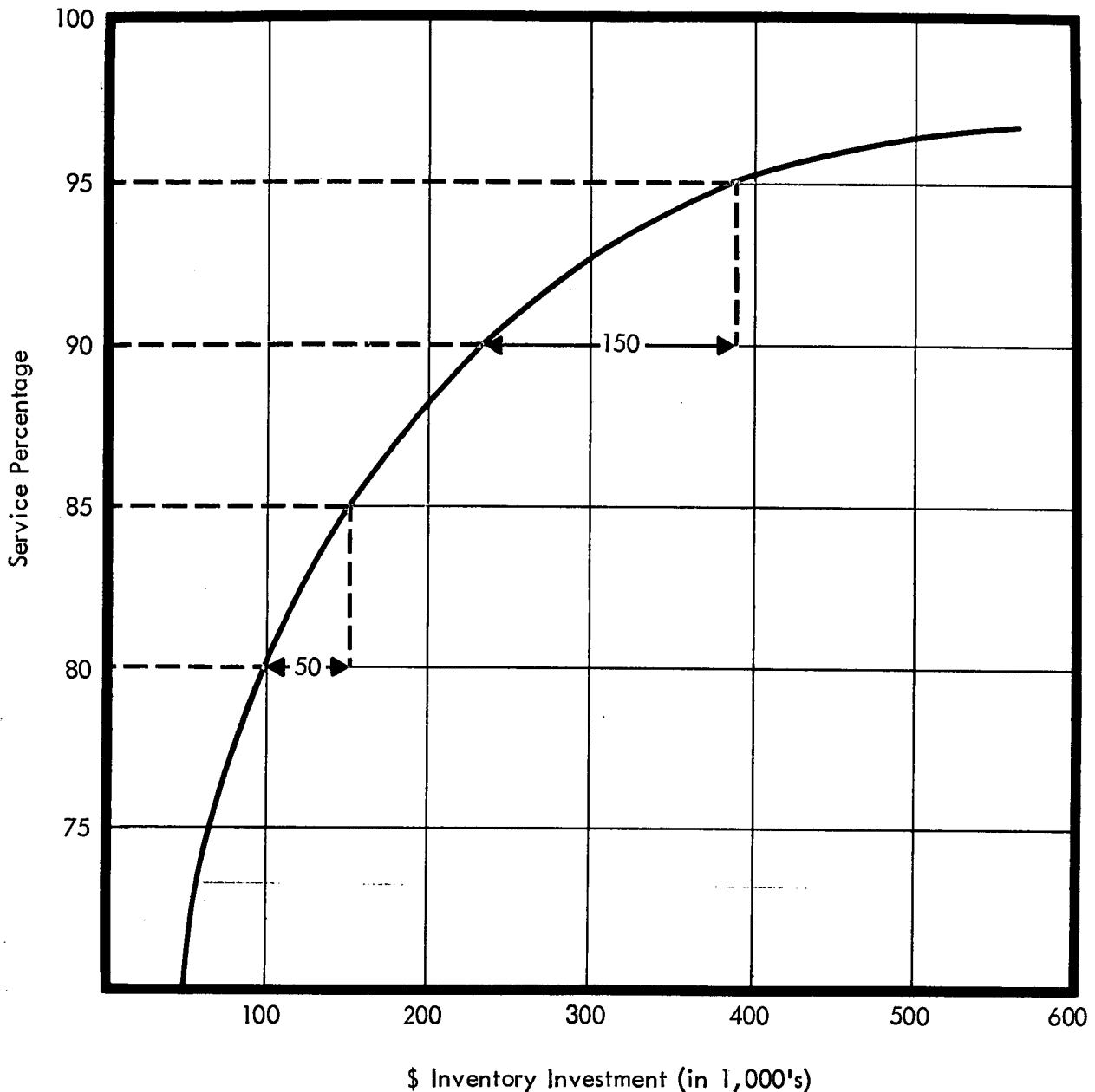


Figure 20. Inventory investment required for various service levels.

Since her demand is absolutely predictable and constant, she can satisfy it by purchasing seven cans of food each time she goes to the store. If she wished to minimize her investment in cat food, she would carry no safety stock, exhausting her cupboard each week just prior to shopping.

c. Demand for the vast majority of secondary items, however, is neither constant nor

highly predictable. Therefore, to protect against stockouts, the RO includes a stratification designated as a safety level. The safety level quantity in inventory represents a hedge to minimize the effect of normal demand variations, poor forecasts, unforeseen demands, errors in reported asset data, variations in lead times, and similar requirements that might otherwise cause a stockout. However, while the safety level stratification is the only peace-

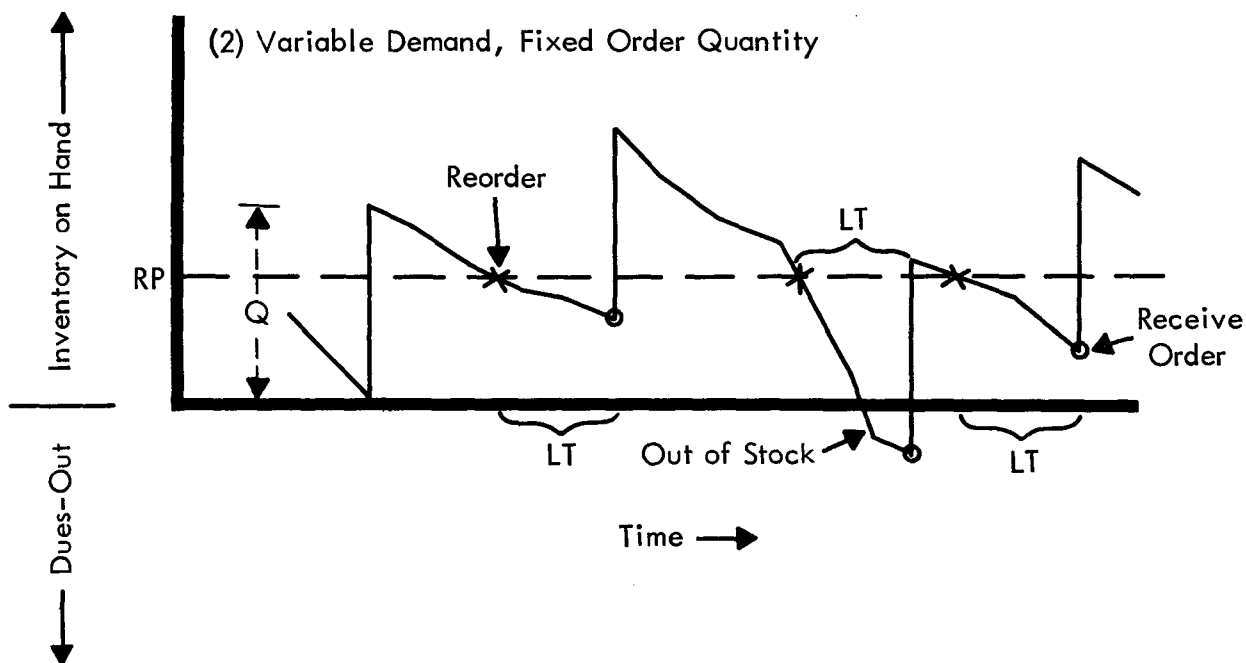
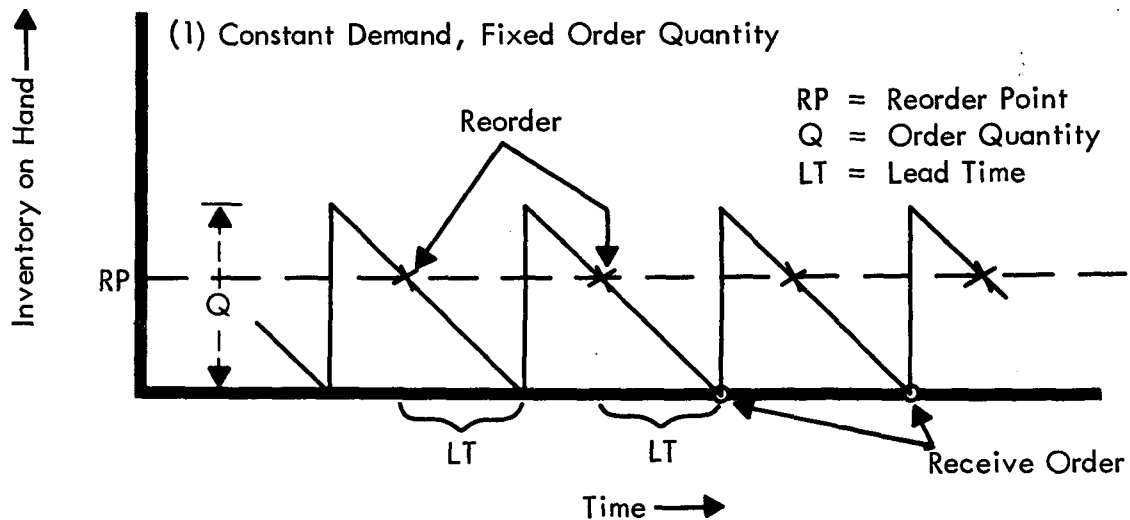


Figure 21. Effect of constant and variable demands on a simple inventory model.

time protective requirement calculated, the safety level quantity is most frequently based upon a consideration of only variations in demand over procurement lead time.

d. Before proceeding to a discussion of why and how safety levels are determined as they are, it should be understood that it is never possible to provide 100 percent protection

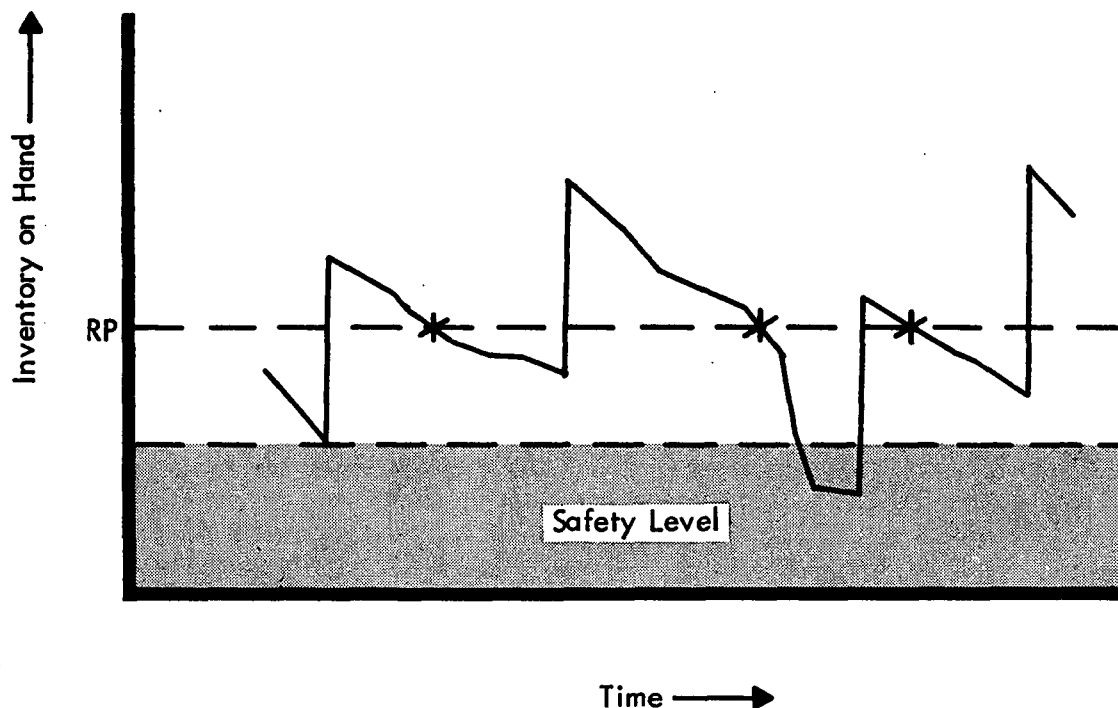


Figure 22. Variable demand with a safety level stratification ("Q" model).

against stockouts for all items. A slight possibility exists that, no matter how large the inventory, demands may occasionally exceed supply. In this regard, the law of diminishing returns is applicable to supply performance (measured as the frequency with which requirements are met). This point is best illustrated with a Service/Investment Curve as shown in figure 20. In this typical curve, note that the five percent improvement in service level from 80 to 85 percent would require an additional \$50,000 investment in inventory, while a \$150,000 increase in investment would be required to achieve a similar five percent increase from a 90 to 95 percent service level. The use of Service/Investment Curve in performance evaluation and measurement is discussed more fully in chapter 12.

e. The principal purpose of a safety level stratification in the requirements objective is to provide for variations in demand over the replenishment period. The need for such protection is shown graphically in figure 21, through the use of the familiar sawtooth diagram for a simple reorder point, fixed order quantity inventory model. In the 1, figure 21, demand is constant and the reorder point

is equal to the demand over the lead time period. In this case, on hand inventory reaches zero at the instant the replenishment order arrives and no stockouts occur. All of the model elements (reorder point, order quantity, and lead time) remain fixed in 2, figure 21, but in this case demand is allowed to vary. As a result of the fluctuations in demand rate, a stockout occurs. If a safety level quantity were added to the model, as shown in figure 22, it has the effect of raising the reorder point by an equivalent number of inventory units. In this manner the safety level would eliminate stockouts except for infrequent occurrences of extremely high demand.

f. The safety level quantity may be determined arbitrarily or may be based on sound statistical principles. A fixed safety level (FSL), a stipulated number of weeks or months of average demand, represents an arbitrary decision. It provides some protection, but the amount of protection cannot be stated without analysis of historical lead time and demand data. FSL's are used when budgetary constraints dictate minimum stockage levels or whenever a basis for calculation of variable safety levels (VSL) has not been determined.

g. VSL's, on the other hand, are based on statistical principles and provide a predetermined level of protection against stockouts. The historical demand pattern for an individual item generally approximates one of several classical frequency distributions. Three common frequency distributions are the Normal, Poisson, or Negative Binomial. The mathematical properties and the applications of these distributions and others are discussed in chapter 16. At this point, it is noted only that the measure of the variation of individual values (demands) about the average value (mean) of a distribution may be provided by a statistic known as the standard deviation. For certain common distributions, the probability of occurrence of a particular demand is related exactly to the standard deviation. Therefore, after determining the size of the standard deviation, a safety level equivalent to a fixed number of standard deviations may be chosen that will provide a predictable level of protection or service. For example, if the distribution is normal, a safety level equal to two standard deviations of demand over lead time will provide protection against stockouts approximately 975 times out of 1,000, or 97½%.

h. If both lead time and demand rate vary during replenishment cycles, the determination of safety levels becomes more complicated. In this case two frequency distributions are involved—one for demand and another for lead time. Even if both distributions are known (i.e., Normal, Poisson, etc.), the relationship of safety level to stockouts cannot be solved analytically without considerable effort, if at all. Inventory models that have treated variations in both lead time and demand have made use of a technique known as Monte Carlo simulation. In summary, it should be recognized that a highly variable lead time will have a significant effect on supply performance, that techniques are available to determine how much safety level is required to provide protection for these fluctuations, and that these techniques are complex.

i. It has been stated that a safety level provides protection over a selected time period, normally the procurement lead time (PROLT) discussed further in paragraph 67. PROLT be-

gins when the supply control study is initiated. A time stratification that is not included in PROLT is the stock status lag time (SSLT). This is defined as the time elapsing between the cutoff date of the stock status reports being used for asset data in a supply control study and the date of the study. When overseas asset data are used in a supply control study, the SSLT may be one month or longer and should be reflected in the requirements calculation as a separate entry. Consideration of SSLT is particularly important in the case of HDV items because these classifications always make use of the Major Oversea Depot method.

j. Occasionally, as the result of a supply management decision or of the manipulation of an inventory model, a safety level quantity will be established with a negative value. Negative safety levels arise for one of two reasons—

- (1) Setting the desired availability at a relatively low level. A negative safety level may be required to hold the system in an out-of-stock condition for a period of time long enough to achieve a desired availability target. For example, if supply management elects to respond to a funding constraint by lowering availability performance to 0.50 (i.e., out-of-stock half the time), a negative safety level would probably be needed to obtain this result. The substitution of a negative safety level quantity for one that was previously positive has the effect of increasing other asset stratifications, thereby postponing a supply control action or reducing the size of a procurement or rebuild order.
- (2) The influence of large reorder cycle quantities on an inventory model calculation. The Massachusetts Institute of Technology (M.I.T.) model incorporates a treatment of the interrelationships existing between the reorder cycle and the reorder point. When reorder cycles are long relative to procurement lead times (e.g., two or more times as long), use of the M.I.T. model may result in a negative value for the safety level even though a high availability level has been established. For

example, when the M.I.T. model is used with the following parameter values:

Unit Price	\$0.10
Annual Demand	10,000
PROLT	6 months
Holding Cost	20 percent
Ordering Cost	\$100.00
Desired Availability	0.90

a safety level of minus 750 units is obtained. In this case, the reorder quantity of 11,600 units serves to hold the system in stock for too long a period to achieve the 10 percent out-of-stock condition established as a desired availability. A negative safety level is therefore required to meet the out-of-stock target. The relationship between safety levels and reorder cycles is discussed in more detail later in this chapter (fig. 24) as well as in chapter 9.

67. Procurement Lead Time (PROLT)

a. Procurement lead time is best described by defining the three elements which, taken collectively, comprise it.

- (1) *Administrative Lead Time (ALT)*. The time interval between the initiation of the supply control study and the award of an order or contract to a commercial or government production facility.
- (2) *Production Lead Time (PLT)*. The time interval between the award of an order or contract and the completion of manufacture or rebuild of the items for the first scheduled shipment.
- (3) *Delivery Lead Time (DLT)*. The time interval between completion of manufacture or repair of an item and receipt of the first scheduled shipment into the supply system, and entry on accountable records.

b. Note that the repair cycle for rebuild items (repairables) is roughly synonymous with the procurement lead time for nonrepairable items. It contains all three elements defined above (with production lead time more

specifically designated repair lead time). However, it also contains a fourth element, accumulation time. The time interval between the return of an unserviceable repairable item to the supply system and the initial scheduling of the item for repair action is termed accumulation time. The definition describes the purpose of this time interval as that time normally required to accumulate sufficient items to constitute an economic rebuild lot.

c. Administrative lead times (ALT) are to be used in the preparation of supply control studies. However, whenever ALT's exceed 3 months, the causes will be examined and justified. While this 3-month period was intended to be treated as a maximum, an analysis of numerous DA Form 1794 studies for MDV and HDV items would suggest, by the preponderance of 3-month ALT's that this length of time is being improperly used as a standard. Use of an unrealistic standard ALT results in an inaccurate statement of requirements and is a primary factor causing items to reach a critical supply position. To keep the ALT to a minimum, NICP's generally initiate procurement action before studies are forwarded to higher echelons for review. When forwarding supply control studies for review a copy of the purchase request is attached and includes the statement "Subject to approval prior to award." Normally procurement is not delayed by higher echelon review. However, the supply analyst and commodity manager are the individuals in the system who should be most keenly aware of the effect of prolonged ALT's on investment in inventories and, indeed, on the service level of supply performance. They should therefore insure that realistic ALT's are used in studies, and then they should follow up during the administrative process as necessary to achieve the best attainable results. Followup actions may be triggered by ADP.

d. Production lead times (PLT) may be as short as a few months or as long as several years. PLT's, because of this wide variance in duration, warrant especially close and individual analysis. Average PLT's for groups of items or cursory estimates must not be used. Rather, to increase the accuracy of PLT's analysis should be made of actual experience on the last two or three procurements and/or

contracts (through procurement channels) made with a known supplier to obtain his best estimates of PLT.

e. Delivery lead times (DLT) are generally direct functions of distances and modes of transportation. As the location of the manufacturer and depot are fixed and the mode of transportation is normally dictated by the configuration of the unit pack, DLT is not often subject to control by the NICP. Lack of control over DLT's does not constitute too significant a problem, as DLT's are usually the shortest element in the procurement lead time, averaging about one month. Nonetheless, every effort should be made to hold DLT's to the shortest time practicable.

f. Chapter 7 discusses costs associated with supply management. It is sufficient to state here that in supply management, time can often be equated to dollars. The length of the PROLT directly affects procurement quantities and the size of the variable safety level. The generalization that investment funds can be saved by reducing procurement lead times (other factors remaining constant) should be constantly kept in mind when preparing supply control studies and directing procurement or rebuild actions.

g. Supply control personnel should be aware of special procurement arrangements that may from time to time be appropriately recommended for the consideration of procurement officers. Examples include—

- (1) Reduction of ALT, PLT, and/or DLT through expediting actions.
- (2) Sole source negotiation, to reduce both ALT and PLT, may be justified under certain circumstances.
- (3) Long-term, multiple-delivery contracts (multi-year procurement) with quantity options (range bidding) to reduce ALT and PLT, ordering costs, and, in some cases unit costs.

h. Perhaps the key conclusion to draw from the above discussion of procurement lead time is the need for close and cooperative working relationships between supply management and procurement personnel. Both groups should be aware of the objectives, problems, and limitations of the other. It is of utmost importance

that as new systems, procedures, and techniques are conceived and developed, they be evaluated in light of their effect on the overall logistics system.

i. The foregoing comments concerning the requirement for close coordination between supply and procurement are equally applicable, in the case of repairable items, to the relationship that must exist between supply and maintenance.

68. Reorder Cycle (REOCY)

a. There are two basic inventory control models. One is based upon ordering a fixed order quantity (Q) and the other upon ordering once every fixed order period (P). The Army presently makes use of both models, but in neither case is a pure Q or P model applied. LDV items are most frequently procured in economic order quantities representing one or more years of average demand. The model for LDV items closely approximates the classical Q model. On the other hand, most HDV items, particularly repairables, are generally analyzed every 3 months, at which time a procurement or rebuild action is directed. The analyses undergone for these items more closely resemble the P model. Thus, the Army uses parts of both models but operates under budgetary constraints more rigid than either basic model contemplates.

b. A sawtooth diagram was used in figure 22 to illustrate the purpose of a safety level. The model shown in this diagram was a Q model, and reference to the figure will clearly indicate that, with random demand, the reorder cycle is variable and a function of the demand rate.

c. A P model, again with random demand is shown in figure 23. Examinations of the above figure will show that the review cycle remains constant, but that a different quantity is ordered each time an order is placed. When the P model is used, it is necessary for control purposes to determine a replenishment goal or point. This quantity, designated RO in figure 23, is equivalent to the requirements objective at the NICP level and the requisitioning objective of field stockage points.

d. When an order is placed for a single de-

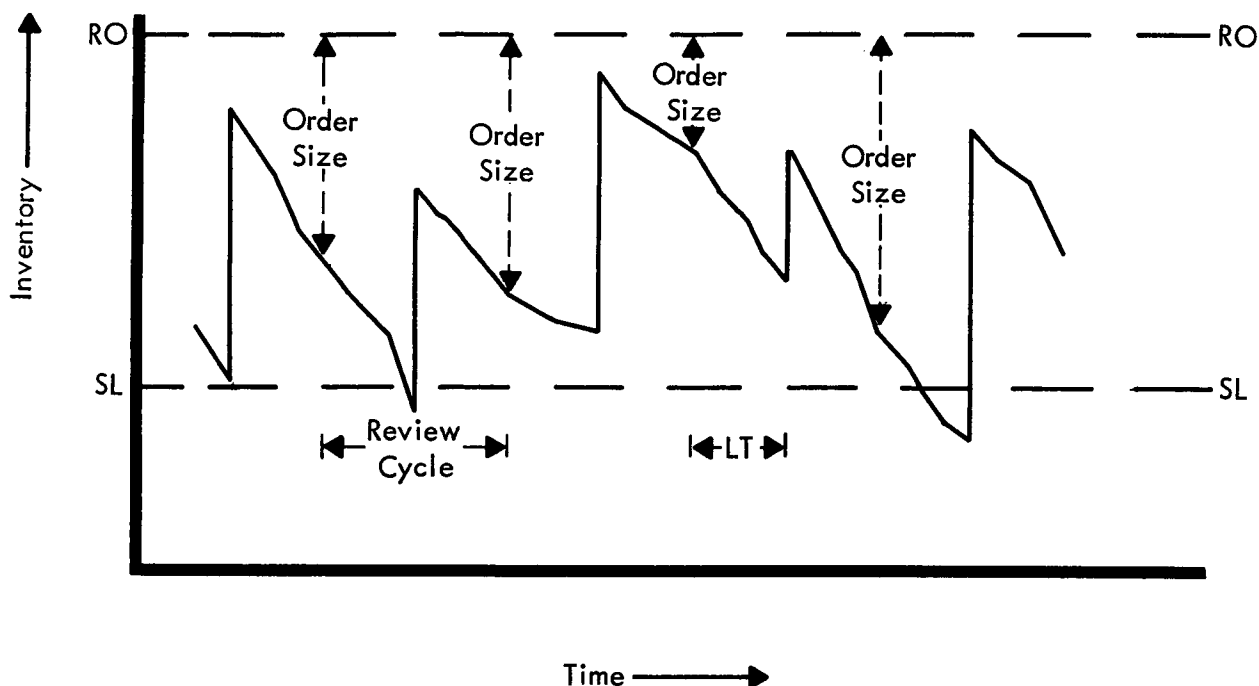


Figure 23. Example of a fixed reorder period model (P model).

livery after each review, the reorder cycle quantity is equivalent to the operating level quantity. That is, based upon usage since the last review, the reorder cycle quantity represents the best estimate of the quantity that will be demanded during the forthcoming review cycle. In this way, REOCY quantities are used to sustain operations at the current level and maintain inventories above the safety level.

e. The order quantity is therefore directly related to the length of the review cycle. If an item is reordered every month, the average order size will represent a month's usage. On the other hand, an annual review cycle will dictate an average procurement of a year's supply. In this manner, the length of the reorder cycle in a P model bears directly on the average investment in inventory.

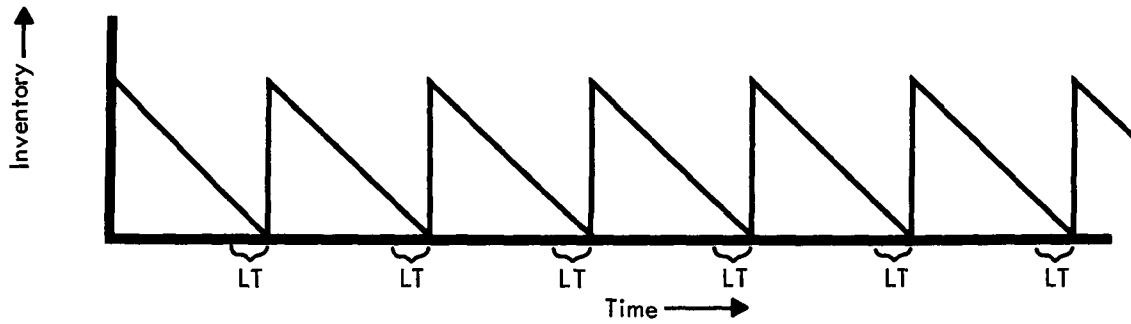
f. In a similar fashion, the REOCY affects the size of the safety level. The safety level, it will be recalled, provides protection against stockouts due to random variations in demand during the lead time period. Figure 24 illustrates relative to time for two items with identical lead time and usage rates but different order quantities.

g. While figure 24 has been used to illustrate that a relationship exists between order quantity and safety level (also see ch 9), it should not be concluded from this example that larger order sizes are good because they reduce safety level quantities. In figure 24, the average operating level for item B was six times that for item A. It is relatively infrequent that variations in demand for an item are so extreme that the safety level exceeds the operating level in terms of numbers of stocked items. It can be assumed, therefore, that the average on hand inventory (one-half the operating level plus the safety level) for item B greatly exceeded that for item A.

69. Dues-Out

a. Dues-out should be considered during the analysis of requirements as they represent an obligation against anticipated receipts. Dues-out arise when a legitimate demand (requisition) is received for an item temporarily out-of-stock and the supply point elects to back-order the items for the consumer instead of returning the requisition as unfillable. It is apparent that the relative inventory status of a stocked item in a due-out position is worse

Item A: Order Cycle = 1 Month Supply
Lead Time = 1 Week



Item B: Order Cycle = 6 Months Supply
Lead Time = 1 Week

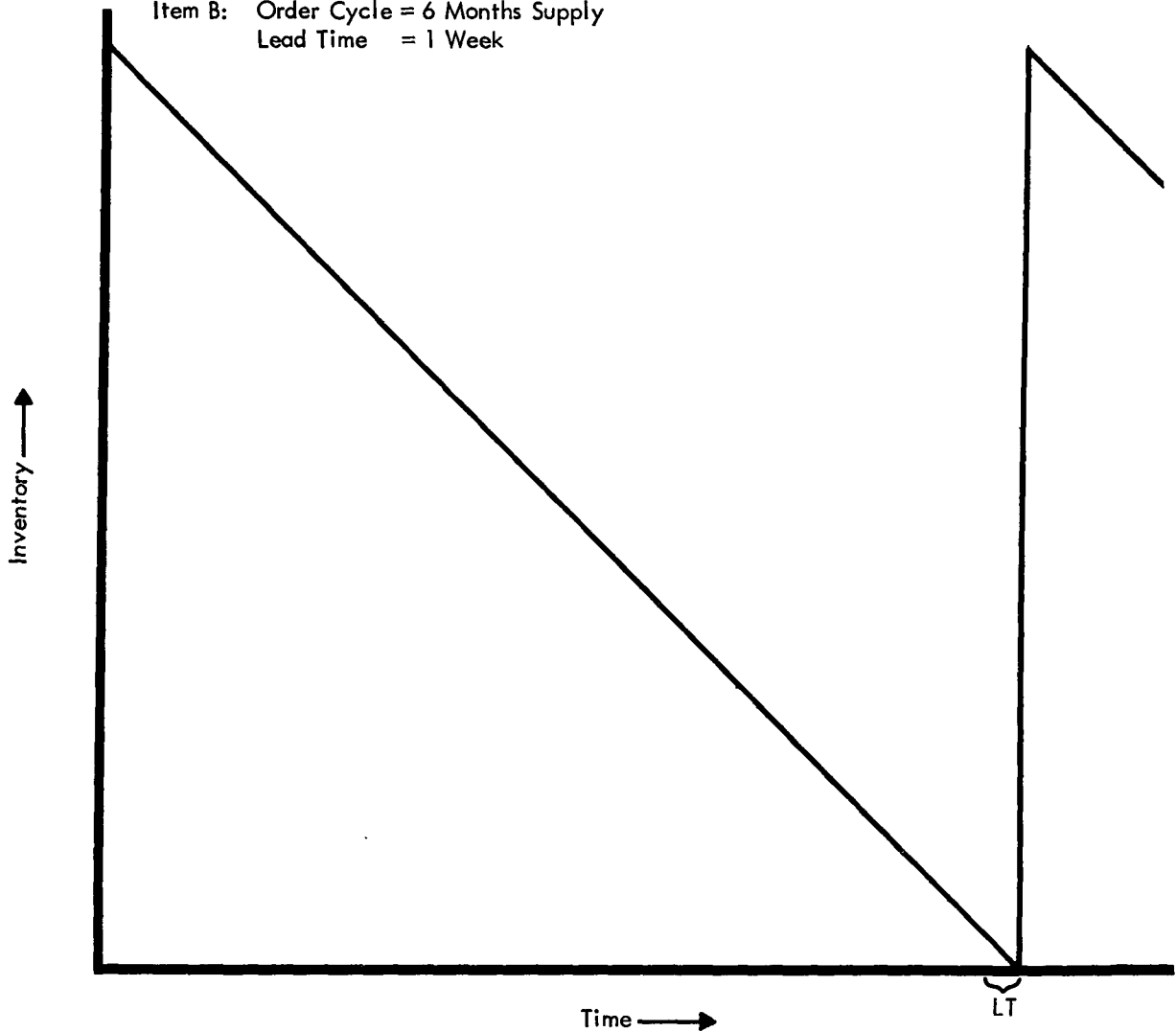


Figure 24. Exposure to stockouts of items with different order quantities.

than that of another item with a zero on hand balance. Dues-out can be properly thought of as negative inventory quantities.

b. Dues-out must be included in requirement calculations. They represent an unfilled historical demand that must be filled during the forthcoming planning period in addition to the normal demands that will be placed in the same period.

c. A useful manner of measuring the performance of a supply system is the average customer waiting time for stocked items not filled by the initial source depot. It is apparent that the availability of an end item is a function of both how often and how long essential secondary items are out-of-stock. Average wait times may be reduced by filling back orders on a priority basis before filling new demands. On the other hand, other accepted measures of supply performance are percent initial fill and percent of requisitions satisfied on time. These indexes can be improved by assigning a low

priority to the filling of dues-out that have already contributed their black mark and which are not counted more than once. In this instance, the measures of performance are contradictory.

d. It might appear that (all things considered equal) it would be best to fill the longest standing request (due-out) for an item first, and then to fill subsequent requests in the order received. However, such a generalization presumes either that the military essentiality of all requisitions is equal or that we have no practical way of determining it on a rank-order basis. This is not true. The priority handling codes contained in the MILSTRIP procedures represent a step towards a sound basis of allocating limited stocks. Nonetheless, until essentiality considerations are incorporated in integrated inventory, maintenance, and budgeting models, it is unlikely that truly optimum solutions will be obtained in resource allocation problems.

Section III. OTHER STRATIFICATIONS

70. Balance Peacetime Force Materiel Requirement (BPTFMR)

a. The peacetime force materiel requirement (PTFMR) is the requirement through the normal appropriation and production lead time periods. Except for very low dollar value items the PTFMR for secondary items is generally taken as the forecasted demand over a period of 30 months, or 2½ years.

b. The balance PTFMR is then the PTFMR requirement less the requirements objective (RO) quantity. While not required as a stratification for budget/appropriation requests, the balance PTFMR is used on the DA Form 1794 for supply control studies and is reported as an FEA level.

71. Balance Mobilization Reserve Materiel Objective (BMRMO)

a. The BMRMO is defined as the difference in quantity between the total mobilization reserve materiel objective (MRMO) authorized for an item and the protectable mobilization reserve materiel objective (PMRMO). The

BMRMO is indicated on the DA Form 1794 and is reported as an FIA level.

b. BMRMO is further divided into Acquisition Objective (A) and Retention Increment (R). While an authorized requirement level, BMRMO-R quantities are rarely found on hand or on order except for items being phased out of the supply system or in an excess condition. BMRMO-A is a useful management tool when used to gauge the degree of uniformity in buildup among mobilization reserve items. BMRMO-A, however, is not used for justification of peacetime budget appropriation requests.

72. Economic Retention Levels

a. DOD Instruction 4140.24 defines economic retention as: "The quantity of an item for which it has been determined will be more economical to retain for future issue in lieu of replacement of future assets by procurement. To warrant economic retention, items must have a reasonably predictable demand rate. If some part of the assets of an item is to be reflected as economic retention, then no

part of the assets of that item may be reflected as contingency retention."

b. Both economic and contingency retention stocks may exist when items are in a long supply position, but not for the same item because they are held for different purposes—

- (1) Economic retention stocks for peacetime issue or consumption.
- (2) Contingency retention stocks for possible military or defense contingencies. The key point is that otherwise excess quantities may be retained for one or the other of these reasons, but not for both. The economic retention classification is more frequently applied to secondary items.

c. The amount of stock (in terms of years' supply at present average usage rates) held as economic retention varies for individual items. A quantitative analysis is often impossible or impractical. Disposal of long supply items would free storage space for other equipment and supply items and reduce certain inventory expenses such as periodic counting. On the other hand, sale of the excess stocks would normally return only a few cents on the dollar; and if subsequent procurement is required, a considerable loss (sale price versus procurement price) would be incurred. For those reasons, and because of the difficulties of an accurate analysis, an arbitrary number of years' supply is generally stipulated by commands for economic retention stock levels.

Section IV. REQUIREMENTS CALCULATIONS IN OVERSEA THEATERS

75. Recent and Current Developments

a. Both USAREUR and USARPAC have been moving toward greater centralization of supply management responsibilities in recent years and are now operating theater Inventory Control Points (ICP's).

b. Several factors have contributed to centralized operations observed in oversea supply management procedures. Among these, the recent extension of the Command Stock Fund (CSF) to this sphere of operations has changed the supply emphasis from that of a "push" system managed by depots to a "pull" system controlled more fully by the consumers.

73. Military Assistance Program (MAP) Retention

Grants or sales of military supply items are made to friendly foreign governments under the provisions of the Mutual Security Act of 1954. The secondary items being delivered under MAP auspices at any point in time are issued directly from U.S. military stocks on hand. The purpose of the MAP retention stratification, however, is to insure the availability of items from storage rather than through procurement channels so far as possible.

74. Excesses

a. Excess stock is that portion of the quantity on hand which is above all known requirements and authorized retention levels. Once excess stocks have been clearly identified as such, they should be disposed of as promptly as possible to conserve storage space, to eliminate unnecessary materiel handling and paperwork, and to retain maximum obligational authority in the Army Stock Fund (ASF).

b. Procedures exist that will insure that all excess items are identified and evaluated prior to classification as surplus. Disposal actions are currently reviewed by the Defense Logistics Services Center (DLSC), DSA, and the other services before implementation. This review provides assurance that one arm of DOD is not procuring an item that another arm is discarding.

c. New reporting and issuing systems, principally TAERS and MILSTRIP, are also facilitating changes in oversea supply management techniques. A centralized control system must be based on accurate, timely and standardized procedures. These new reporting and issuing systems are contributing to this end.

76. Selective Management

a. Items carried on oversea stockage lists are divided into inventory classifications for purposes of selective management in much the same way as directed for CONUS NICP's. For example, the Supply and Maintenance Agency

of COMMZ, USAREUR, has four major inventory classifications for transportation, air, and surface items, each of which receives a different management emphasis—

<i>Classification</i>	<i>Review frequency</i>
(1) Special management and critical items -----	Monthly
(2) Repairable air and surface items -----	Quarterly
(3) Nonrepairable air and surface items -----	Semiannually
(4) Economic Order Quantity (EOQ) items -----	Annually

The approximate equivalents of these classifications are, respectively, HDV, MDV, and LDV.

b. The log normal distribution analysis recommended for NICP's in chapter 3 should have comparable application to overseas theaters after centralization has been accomplished.

77. Oversea Requirements

a. Valid, procurable overseas requirements are stratified for analysis and control purposes. The overall requirement is again designated as an RO, but in this case it signifies a requisitioning objective as distinguished from the previously discussed requirements objective.

b. The elements of the overseas RO are—

- (1) Peacetime operating level
- (2) Safety level
- (3) Order and shipping time (OST) or procurement lead time
- (4) Mobilization reserve quantity.

c. The operating level is analogous to the reorder cycle quantity of CONUS NICP's. Current overseas directives stipulate that the operating level be equivalent to 12 months of average demand for EOQ items and 30 days of supply for all other items. It is presumed, therefore, that the asset status of the 30-day items is checked at least once a month, even though formal supply control studies might be performed only quarterly or semiannually.

d. Overseas commands are currently using a fixed safety level of 30 days of supply for all items. It is expected, however, that as more data becomes available and managers become

better acquainted with scientific inventory control techniques, more uniform protection over order and ship time (OST) or PROLT will be provided by the use of statistically based variable safety levels. It should also be noted that fixed safety levels are deleted from RO quantities when a theater reserve requirement is on hand that exceeds 30 days of supply. This practice is questionable (within the context of budgetary limitations), since mobilization reserves are provided for wartime contingencies whereas safety levels are intended to insure a selected level of peacetime supply performance (e.g. if theater reserve were 2 years or more supply the 30 day safety level could be deleted).

e. Order and shipping times as used in overseas RO's are the counterpart of the procurement lead time used by CONUS NICP's. The order shipping time represents the time interval between the asset review and receipt of the materiel ordered from CONUS supply points. Most overseas agencies base order and shipping times on low priority MILSTRIP standards or upon a consideration of historical experience.

f. Procurement lead time is included in overseas RO's only when CONUS nonstocked items are required for programmed maintenance or other special requirements. In these cases, the overseas agency generally contacts the appropriate CONUS NICP for an estimate of the PROLT.

g. It is anticipated that with present trends relative to centralized management, improved data and data processing capabilities, and increased research of the logistics system, more application of scientific inventory control techniques will be observed in overseas theaters in future years. These improvements may reduce the data requirements of the CONUS NICP's and simplify their supply control studies (DA Form 1794) (for example line inputs to CONUS NICP studies). Further, the use of more scientific inventory control techniques in overseas theaters should result in increased control over the entire supply pipeline.

CHAPTER 7

COST CONSIDERATIONS

Section I. GENERAL

78. Introduction

a. It has often been stated that the fundamental difference between governmental and commercial organizations is that only the latter are motivated by an incentive for profits. The basic premise, absence of a profit motive in public agencies, is true; the frequently derived implication, however, that the military departments and other agencies of the Federal Government are not conscious of costs, is patently false. For example, the lack of a profit entry on an annual operating statement makes the Department of the Army's performance evaluation task more difficult, but, nonetheless, a consideration of cost is invariably a factor in all important DA decisions and is reflected in most DA control systems.

b. Maintenance of the military posture of this nation is the primary objective of the Department of Defense. For this reason, concern for costs is sometimes properly relegated to a role of secondary importance. However, even where questions of military essentiality receive special emphasis, cost considerations have a significant effect on final decisions.

c. There have been many evidences in recent years of increased emphasis on costs by DOD and DA—particularly regarding program planning and as a measure of value received for funds expended. Examples include—

- (1) Five-year force structure and financial planning.
- (2) Cost-effectiveness evaluations.
- (3) Financial management plan.
- (4) Annual cost reduction programs.

The success of the above programs and techniques, combined with an expected continuation of the cold war environment, indicates a further emphasis on cost consciousness in the future.

79. Types of Costs

Accountants often divide costs into three general classifications for purposes of analysis and allocation.

a. Variable Costs. Those costs that vary directly and proportionately with the volume of work performed. Examples include charges for experienced direct production labor and the cost of the materials (excluding price break considerations) that go directly into the finished product.

b. Fixed Costs. Those costs that do not vary with the volume of work and that normally can be eliminated only by discontinuing (liquidating) an activity. Examples include administrative overhead and fixed asset depreciation.

c. Semivariable Costs. Those costs that are neither directly variable nor fixed. Semivariable costs increase with a greater volume of work, but not in direct proportion. Electricity and fuel costs frequently fall under this classification.

Note. Costs must be classified in the above manner before they can be appropriately utilized in detailed analyses of supply management costs.

80. Sources of Funds

a. Cost analyses tend to be simpler in industry than in government. A dollar is a dollar (allowing for inflationary influences), irrespective of how or when it is spent. In the Army, however, different funds are allocated for specific uses. Stock fund money is used to purchase equipment and supplies, while Operation and Maintenance, Army (OMA) money is used to operate the supply system. Other funds utilized in the overall logistics system include—

- (1) PEMA (Procurement, Equipment, and Missiles, Army).
- (2) CSF (Command Stock Fund).

- (3) MPA (Military Personnel, Army).
- (4) MAP (Military Assistance Program).

b. Each of the above funds has not only a well-defined (restricted) application, but other important distinctions in addition. For example, stock funds are revolving in character (inventory purchases are debited, consumer sales credited), whereas the others represent annual appropriations. The funds are managed in different offices at both the DA and Bureau of Budget levels. The funds also differ in degree of availability, at budget approval time as well as during the fiscal year.

c. The inventory control models discussed throughout this manual require consideration of all these kinds of funds. However, because of analytical simplification, these models do not differentiate between types of funds. For this reason, it is both necessary and fitting that supply management personnel frequently apply subjective judgment when evaluating alternate courses of action, even those indicated by a scientifically based analysis of requirement and asset data.

81. Cost Objectives

a. The basic objective of the logistics system might be stated as, "Get the right item to the

right place at the right time at the least cost." (The relationship of performance to cost is discussed more fully in ch 12.) Cost considerations generally, if possible, lead to the development of a mathematical expression whose solution minimizes total cost at an acceptable level of performance. The problem arises in establishing the relevancy of the total cost figure. Such questions as follow should be asked:

- (1) Are total costs to be minimized on an annual basis or over an indefinite time interval?
- (2) Whose total costs are to be minimized—the theaters? the Army's? DOD's?
- (3) Should cost optimization cut across fund boundaries?
- (4) Are variable costs truly variable and fixed costs really fixed?

b. These questions will be discussed in an appropriate context in many sections of this chapter. Some cannot be completely answered at this time. Supply management personnel should attempt to direct supply actions in a manner that minimizes the total cost of the logistics system over a reasonable time frame (3 to 5 years), realizing that some decisions will necessarily be both controversial and suboptimum.

Section II. ORDERING COSTS

82. Introduction

a. There are several cost factors to be considered in any analysis of the policies and procedures of supply management. These costs are generally subdivided into three distinct functional areas—

- (1) *Ordering costs.* The costs of operating the replenishment system.
- (2) *Holding costs.* The costs associated with the physical presence of the goods in inventory.
- (3) *Out-of-stock costs.* The implied costs of shortages or the failure to meet legitimate demands.

b. This section is devoted to a discussion of ordering costs. The two remaining cost classifications are treated separately in paragraphs 89 through 95 and 96 through 99.

83. General

a. Ordering costs are those costs directly associated with placing an order with a vendor or production facility. This cost classification includes, at a minimum, the following elements:

- (1) Supply, stock, and financial control elements.
- (2) Contract placement and administration, including inspection and acceptance.
- (3) Control and documentation incident to shipment and receipt.
- (4) Setup costs, as applicable.

b. Whenever ordering costs are applied in total cost optimizing equations, only the variable and semivariable portions of the cost element are included. If a change in the level of the procurement activity does not affect a given element of operating costs, the cost should be identified as a fixed cost and excluded from all calculations of total variable cost.

c. Variable ordering costs are normally incurred by four separate organizational units.

- (1) The supply management activity (NICP).
- (2) The procurement activity (regional office or part of NICP).
- (3) The receiving activity (CONUS depot).
- (4) The supplying activity (costs reflected in manufacturer's unit price).

d. The functional costs that should be examined at each location are discussed below.

84. Supply Management Ordering Costs

a. The NICP incurs ordering costs associated with supply, stock, and financial control actions. The magnitude of these costs has been observed to be a function of the type of order document ultimately utilized at the conclusion of an ADPS or manual supply control study. Three such documents in common use are—

- (1) Small purchase procurement directive (PD) (<\$2500).
- (2) Large purchase procurement direction (>\$2500).
- (3) Requisition procurement (emergency procurement of shelf items, (<\$25,000).

b. Examination of ordering costs incurred by several NICP's revealed that the variable costs average approximately \$20 per order for small PD's and requisitions and about \$40 per order for the larger PD's. The cost elements included in these variable costs are—

- (1) *Direct labor.* Operating personnel immediately concerned with the ordering process.
- (2) *Direct material.* Primarily stationary supplies consumed as a result of the ordering process.
- (3) *Direct charges.* The cost of ADPS, electronic accounting machines (EAM), communications, reproduction, and technical information services.
- (4) *Direct overhead.* Supervisory personnel up to the Deputy level. Portions of this cost were sometimes treated as semivariable or fixed.
- (5) *Office equipment.* Depreciation charges on basic office furniture and equipment. Sometimes treated as fixed.
- (6) *Space costs.* Building depreciation, repair, and utility charges as furnished by

the General Services Administration (GSA). In an analysis of short-term ordering costs, building depreciation should be treated as fixed and other space costs as semivariable.

- (7) *General overhead.* Outside activities such as the Legal Office, Inspector General (IG), Small Business Office and the like should be treated as fixed costs and should be ignored as a variable cost.

85. Procurement Ordering Costs

a. Included in this category are both the costs associated with the ordering activities of the Procurement Directorate of an NICP as well as those of regional procurement offices. The functions performed in this area include preparation of detailed specification, advertising, bid reviewing, and negotiation.

b. Previous studies have indicated that this group of activities contributes variable costs per order of the following magnitude:

- (1) Small PD's—\$25 to \$50
- (2) Requisitions—\$50 to \$100
- (3) Large PD's—\$200 to \$700

c. The accounting cost elements included in this group of ordering costs should normally be the same as those listed in paragraph 84. Care must be exercised, however, to insure that costs incurred by regional or central procurement offices are included in any NICP directed analysis. These "outside" costs can be a significant portion of the total ordering costs.

86. Ordering Costs of Receipt and Inspection

a. CONUS depots, which takes delivery of ordered items, incur costs that are a function of the number of receipts a year. These costs are therefore variable in the context of this discussion. For example, there are documentation, handling, and inspection activities which must be performed once per shipment regardless of the lot size.

b. The ordering costs in the field have been studied in some depth based upon an elemental cost accounting breakdown similar to that outlined in paragraph 84. Variable costs per order were determined *not* to be a function of type of procurement directive, but constant and of the order of magnitude of \$10 to \$15 per order. Under

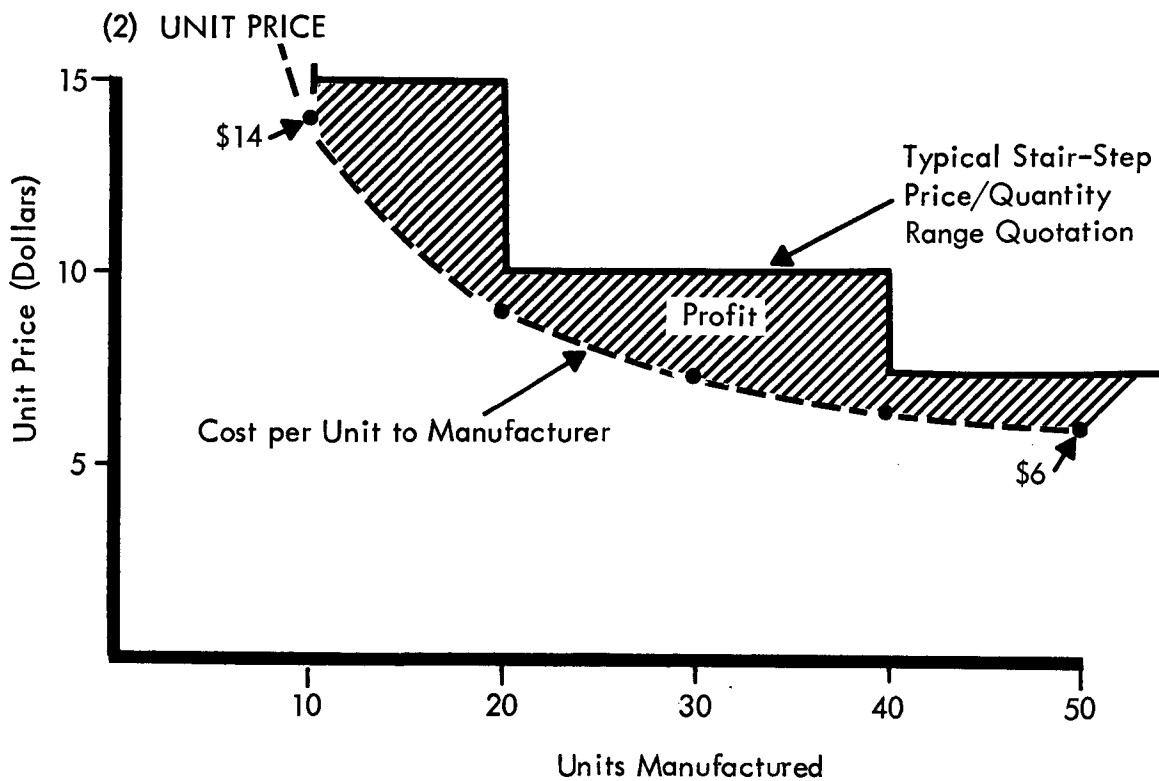
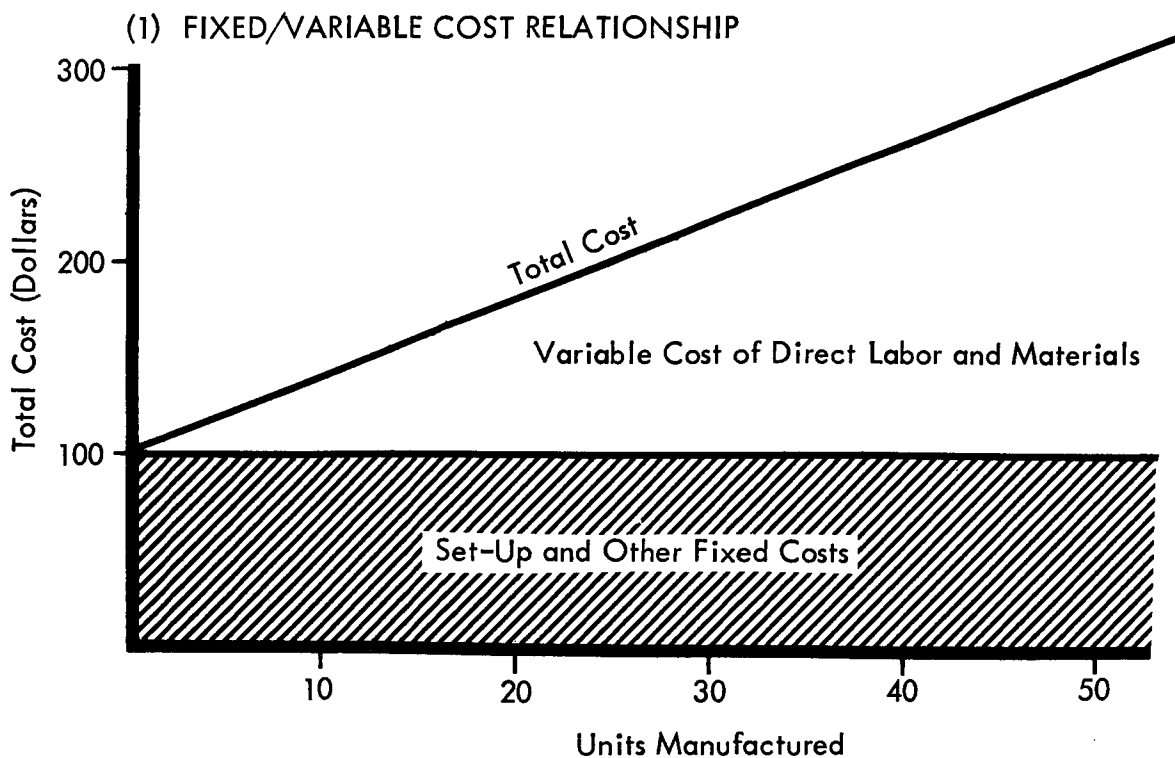


Figure 25. Effect of manufacturing setup cost on unit price.

The Army Supply and Maintenance System (TASAMS), CONUS depot ordering costs may be eliminated as control is shifted entirely to the NICP.

87. Setup Costs

a. Manufacturers will often quote quantity discounts if asked to do so in a bid request. The manufacturer can do this because he too has fixed and variable costs associated with the number and size of orders he receives. As unit price/quantity relationships are therefore a function of the frequency of ordering a stock item, these costs are normally included in the ordering cost grouping.

b. The manufacturer's fixed setup costs determine the amount of the quantity discount he can offer. Setup costs include the labor and other expenses of procuring an order, initiating a production run, and, in many cases, the costs of lower production and higher reject rates in the early phases of production.

c. The relationship between setup and other fixed costs and unit price is illustrated in figure 25. The upper graph, 1, figure 25, shows how total production costs are a function of the fixed cost (\$100) and variable cost (\$4/unit) for various order sizes (ranging from 0 to 50 units). The dashed line in the lower graph, 2, figure 25, indicates how, in this example, the cost per unit to the manufacturer drops from \$14.00 if 10 units are produced to \$6.00 if the order is for 50 units. The stair-step solid line in the lower graph represents how the manufacturer might bid the job on a price/quantity range basis (i.e., 10 to 20 units \$15 each, 21 to 40 units at \$10 each, 41 units at \$7.50 each). The shaded part of the lower graph represents the per unit profit the manufacturer would make dependent on the size of the order.

d. Whereas all other elements of ordering cost may be incorporated in a generalized inventory model for automatic solution of minimum total cost problems, proper consideration of setup cost requires application of specific data for individual stocked items. One method of indirectly obtaining information on manufacturers' setup costs is through range bidding procedures. By requesting price quotations on lots of varying size, the fixed and variable price portions may be imputed. A discussion of the ways of computing a minimum cost solution for items with significant price/quantity breaks is contained in chapter 8.

88. Development and Use of Ordering Costs

a. The ranges in the variable costs of ordering previously discussed are summarized in table 13.

b. It is apparent from table 13 that ordering costs can vary significantly depending upon the size of the order (\$) and the efficiency of the supply and procurement activities. For this reason, it is generally desirable that any organization contemplating the use of economic inventory control procedures develop its own ordering costs based upon an analysis of its specific operations.

c. The effect on economic order quantities of using ordering costs which are either too high or too low is discussed in chapter 8. It is shown that errors of ± 20 percent do not significantly affect EOQ's. Estimates of local variable ordering costs to an accuracy of ± 20 percent should be attainable without undue effort as long as all important cost elements are considered. On the other hand, a laboriously detailed analysis of ordering cost elements is rarely justified because of the relative insensitivity of total variable annual costs to changes in one factor as well as the built-in need for a subjective division of elements into the variable, semivariable, and fixed cost classifications.

Table 13. Summary of Variable Ordering Costs

Summary of Variable Ordering Costs

	Small PD's	Requisition Procurements	Large PD's
Supply management costs	15-25	15-25	30-50
Procurement costs	25-50	50-100	200-700
Receiving costs	10-15	10-15	10-15
Setup costs	Normally individually determined		
Total	50-90	75-140	240-765

Section III. HOLDING COSTS

89. General

a. Holding inventory implies two general types of costs—that associated with the physical presence of the material in storage, and that of the capital tied up in inventory. The first of these costs includes both fixed and variable components, while the second, cost of capital, is entirely variable.

b. For purposes of discussion and analysis, it is convenient to divide holding costs into five principal elements:

- (1) General storage costs.
- (2) Deterioration.
- (3) Obsolescence.
- (4) Losses.
- (5) Interest.

90. General Storage Costs

a. Included in the broad classification of general storage costs are—

- (1) Clerical and administrative costs of accounting for stock held in inventory.
- (2) Costs of conducting periodic (often annual on a staggered stocked item basis) physical inventory counts.
- (3) Special costs of care and preservation related to holding material in storage

for long periods of time (i.e., special packaging, air conditioning or dehumidification, cleaning before issue, etc.).

- (4) Cost of the storage space occupied by the items in inventory. This element is often determined to be a fixed cost and, as such, is excluded from holding cost calculations. Storage space costs may be variable, however, if a change in stockage policy can be expected to result in a requirement for new facilities (a building to be built or leased) or in the release of an entire building for other useful purposes.

b. For calculation purposes, holding costs are normally expressed on an annual basis as a percentage of the value of stocks held in inventory. For example, if general storage costs are found to be \$2,500,000/year and the average value of inventory was \$250,000,000, the general storage element of holding costs would be calculated as 1 percent. The above figures indicate, as previous studies have shown, that the general storage cost element will range between 0.5 percent and 1.5 percent for typical stocked item mixes.

c. The general storage cost element of holding cost may be accurately determined from cost accounting records if costs can be appropriately

identified as variable, semivariable, or fixed. However, since this element rarely constitutes more than 10 percent of the total holding cost, a detailed analysis is not normally justified. For this reason, general storage costs can generally be estimated at 1 percent unless a significant proportion of items carried in stock is known to require unusual handling in and out of storage and/or special storage facilities which are in limited supply.

91. Deterioration

a. Some items are stocked in inventory to meet recurring demands, to provide mobilization reserves, and to permit economic lot size purchasing, despite a tendency to a short shelf life because of deterioration. Examples of these items are certain types of batteries and chemical munitions. Such items are normally carefully controlled on an individual basis with specially selected and tailored techniques. On the other hand, practically all items evidence some storage deterioration that cannot be economically or completely minimized with turnover (first-in, first-out) controls. For these items (i.e., ones controlled by application of standard economic inventory principles) an allowance for deterioration must be included in an estimate of holding cost.

b. For the majority of holding cost formulations now in use by NICP's, the deterioration element is estimated at 5 percent per year. The use of a figure of 5 percent does not imply that storage life expectancy is 20 years, as would be true only in the case of no stock rotation. Rather, the 5 percent estimate of the cost of deterioration in storage is based upon analysis of a large number of disposal actions and the observed condition of a variety of stocked items held for a varying number of years—hence, a gross average estimate.

c. A 5 percent estimate for deterioration is a satisfactory figure for EOQ calculations of most LDV items. However, whenever EOQ's are to be calculated for MDV and HDV items on an individual basis, some thought should be given to the expected rate of deterioration in storage. A larger or smaller percentage figure for deterioration should then be incorporated as an element of holding cost.

92. Obsolescence

a. The obsolescence element in holding cost is

more properly defined as "surprise obsolescence." Items in stock become obsolete as a result of technical developments that make the use of a better product possible or even mandatory. When product improvements are the result of a long-range Research Development Test and Evaluation (RDTE) program, the entry of the new end item into the supply system can generally be forecasted sufficiently far in advance to permit orderly phasing-out of supporting secondary items. In this case, the holding cost obsolescence element will be zero or very small. However, when a technological "breakthrough" permits rapid implementation of unforeseen equipment improvements, or whenever new weapon systems are introduced into the supply system before design has been standardized and frozen, "surprise obsolescence" of stocked support items occur. A significant allowance for obsolescence must be reflected in the holding cost for items so affected.

b. Most NICP's estimate the surprise obsolescence element of holding cost to run about 5 percent per year of the average investment in inventory. This figure could be interpreted in two ways—

- (1) 5 percent of the dollar value of items in inventory become obsolete each year; or
- (2) the average item in inventory will be subjected to surprise obsolescence once every 20 years.

c. Studies of the inventory costs of several Commodity Commands have revealed that a 5 percent figure for surprise obsolescence is a good overall average. For certain extremely stable items, however, it would be zero; while for fast-moving electronic components a surprise obsolescence rate of 20 or 30 percent might be more reasonable. Therefore, a 5 percent holding cost element may well be used for large groupings of stocked items; but, when items are analyzed on an individual basis, a specific surprise obsolescence factor that reflects actual experience should be selected.

93. Losses

a. Physical inventories of stocked items invariably result in an actual count that is greater or less than that carried in accounting ledgers. On balance, such differences are more often losses than gains. Whereas individual gains and losses may be attributable to inaccurate counts (no real

Table 14. Summary of Ranges of Holding Costs

Summary of Ranges of Holding Costs

<u>Element</u>	<u>Annual Cost as Percent of Dollars in Inventory</u>
General storage cost	0.5 to 1.5
Deterioration	0.5 to 5.0
Obsolescence	3.5 to 33.0
Losses	0.5 to 2.0
Interest	<u>4.0</u> <u>4.0</u>
Total*	9.0 to 45.5

* Total holding costs in actual use range from 10 to 45 percent except for certain low annual demand EOQ items where an artificial holding cost of 100 percent is applied to reduce procurement quantities.

change in asset status), the net effect of a loss is generally the result of pilferage, cannibalization, and unrecorded issues.

b. Losses vary greatly among individual stocked items and are principally a function of their commercial application (pilferage), accessibility and use (cannibalization), and size and value (accurate stock record keeping). In practice, losses, as a percentage of inventory valuation, range from zero to as much as 5 percent. A figure of 2 percent is a good overall average and is used in many holding cost formulations.

c. NICP's may well estimate losses at 2 percent of average inventory investment unless analysis of historical data reveals that another percentage would be more appropriate.

94. Interest

a. DOD Instruction 4140.11 indicated that interest on capital invested in inventory should be treated as a holding cost and established it as 4

percent of average inventory value. The 4 percent figure represents a reasonable good overall average for interest on the various sources of federal funds as they are currently divided between short- and long-term financing.

b. Interest rate constitutes a good measurement of the cost of capital to the Federal Government, which has essentially unlimited credit and can find a relatively stable market for its bonds. It should be recognized, however, that simple interest rate is not normally used as a measure of the cost of capital in the commercial world. Because investment capital is not unlimited, businessmen prefer to think of the cost of capital as an "opportunity" cost, that is, what opportunities exist to improve operations (in the long run, profits) with available capital? If management could invest in a new item of machinery that has a calculated return on investment of 10 percent, but elects instead to procure additional inventory for the purpose of improving delivery performance, the inventory investment cost can be

assumed to be 10 percent—equivalent to the lost opportunity for profit. Most inventory control textbooks treat cost of capital as an opportunity cost rather than as simple interest.

95. Development and Use of Holding Cost

a. Table 14 summarizes ranges in the elements of holding cost as presently applied in least cost formulations by CONUS NICP's.

b. Most NICP's apply a holding cost of 17 percent to the bulk of their LDV items that are ADPS controlled. This figure represents a good

overall average for use until disproved by local cost analyses.

c. The most variable element of holding cost is the rate of surprise obsolescence, as evidenced in the above table. Detailed local analyses of the surprise obsolescence factor should be conducted wherever engineering design changes are commonplace and the rate of technological advance rapid.

d. The sensitivity of EOQ formulas to differences in holding rate is discussed in chapter 8. The use of artificially large holding rates as a device to reflect budgetary constraints is discussed in paragraphs 100 through 105.

Section IV. OUT-OF-STOCK COSTS

96. General

a. Out-of-stock or shortage costs are those costs that arise from situations where the demand temporarily exceeds the supply. In most cases they are very difficult to measure quantitatively and often vary with time as a function of the particular circumstances applicable to an individual shortage.

b. Consideration of out-of-stock costs has been successfully incorporated into several commercial inventory control models. For example, many production control models determine the requirement for repair parts on a basis of the cost of lost production—using either per unit profit or overtime premium charges as a measure of cost. Some mail-order companies accurately estimate out-of-stock costs as a function of the increased cost of expediting back orders, substitution of better quality merchandise, and a higher rate of returns on items back-ordered. Nonetheless, most commercial estimates of out-of-stock costs are recognized as only approximations. The loss of consumer goodwill and of future sales cannot normally be quantitatively evaluated.

c. In the military logistics system, out-of-stock costs differ among the various echelons of supply. The cost or importance of a shortage condition is not the same at the wholesale level as it is to the consumer in the field. Some of the problems of measuring out-of-stock costs as well as some of the solutions that have been proposed are considered below. It will be evident that there is a need for additional research on this subject.

97. Elements of Out-of-Stock Cost

a. Studies of the Army's multi-echelon supply system have revealed that a temporary out-of-stock condition at the wholesale level does not necessarily mean that the consumer in the field will incur a delay in the receipt of replenishment stock. In many cases, the length of the supply pipeline dampens out surges at the national level to the extent that they never affect the ultimate consumer. In such cases, the out-of-stock cost need not include a consideration of the availability of the supported weapon system. Instead, in these instances, out-of-stock cost is only comprised of several measurable cost elements.

- (1) *Unusual order processing costs.* The extra cost of handling a requisition on an emergency basis. Special correspondence, long-distance telephone calls, and the like.
- (2) *Increases in unit cost.* Emergency procurements may result in higher than normal unit costs. The manufacturer may pass along the cost of overtime production, or an absence of competitive bidding may be reflected in a higher price per item.
- (3) *Special material handling.* To reduce the out-of-stock period to a minimum, higher cost modes of transportation (truck versus rail versus air) may be used, or loading and unloading may be performed at premium wage rates.

b. Often a shortage of one item of stock results in the issuance of a different item with measurable adverse cost effects.

- (1) *Substitute items.* Other items may be substituted for the out-of-stock item on a one-for-one basis. The issuance of these items may represent an identifiable cost in terms of unit price, shorter effective use life, or a quantifiable reduction in the effectiveness of the end item.
- (2) *Cannibalization.* A more valuable item of stock may be cannibalized to make available a part that is out-of-stock. For example, the use of a distributor assembly when only ignition points are requested.

c. When the supported end item is actually affected by an out-of-stock condition, additional cost factors are introduced whose evaluation is necessarily more subjective.

- (1) *Downtime.* The cost of being out-of-stock is a function of the length of time the out-of-stock condition persists. This time interval may be difficult to measure or incorporate in a mathematical model.
- (2) *Level of effectiveness.* An end item may not be rendered inoperable by the lack of a repair part but may instead be merely reduced in its effectiveness. A combat vehicle may be of some use, for example, when its radio is malfunctioning.
- (3) *Ultimate system affected.* It has been said that a battle may be lost through want of a horseshoe nail. Often a meaningful analysis of the cost of a stock shortage will require the study of a system that extends beyond the immediate supported end item.

98. Imputed Out-of-Stock Costs

a. As an alternative in attempting to measure actual out-of-stock costs, an inventory model may

be constructed that is based on an "imputed" shortage cost. An imputed out-of-stock cost is determined through a mathematical analysis of the frequency with which a given control system permits shortages to occur.

b. Most inventory models are designed to perform, on the average, at a specified service level. A service level, in turn, is normally expressed as the percentage of time demands will be met from storage (or percent of requisitions that will be filled without delay). The service level is a function of stockage policies, item characteristics, and most particularly the amount of the safety level. A better service level may be obtained by carrying more inventory as safety stock, with however, a resultant greater investment in inventory. The relationship between a given service level and the variable costs of investment in inventory can be computed. This computed cost is the "imputed" out-of-stock cost associated with a specified performance level. An example of such a calculation is contained in chapter 8.

99. Use of Out-of-Stock Costs in Inventory Models

a. Inventory models presently in use at Army NICP's minimize only the combined costs of ordering and holding inventory. Out-of-stock costs are not included in the total variable cost equation.

b. Other DOD agencies have developed models that incorporate a consideration of out-of-stock costs. Two such models are discussed in chapter 13, one was developed for the Navy, and the other is in use by the Defense Supply Agency.

c. Research into the evaluation and application of out-of-stock costs is presently being conducted within the Army. Undoubtedly, further use of this supply system cost element will be made in the more comprehensive, and mathematically more rigorous, inventory models developed in future years.

Section V. BUDGETARY CONSTRAINTS

100. General

a. While the NICP's of the several Commodity Commands centrally direct the procurement, storage, distribution, maintenance and disposal of assigned stocked items, their decisions must often reflect budgetary constraints imposed by the

Department of the Army (DA) and the Bureau of the Budget (BOB).

b. The vast majority of secondary items are purchased with two kinds of money. Some are procured with PEMA (Procurement Equipment and Missiles, Army) funds. Most secondary

item inventories, however, are maintained through the use of the Army Stock Fund (ASF). The ASF operates as a revolving fund in that new procurements are made possible by past sales. An NICP's ASF cash account is credited (increased) as stocks are issued to meet consumer demands and debited (decreased) when dollars are withdrawn to pay for stocks procured from commercial or other sources.

101. Limitations

a. Inventory procurement programs of the AMC wholesale division of the Army Stock Fund are limited by the amount of obligational and commitment (procurement) authority established through the Bureau of the Budget (BOB) apportionment process, whereas procurement programs of retailers are limited by the amount of "acquisition authority" approved by DOD. Although a need for inventory items may exist and cash may be available, an AMC stock fund manager is prohibited from directing procurement actions unless obligational authority has been provided. In approving obligational authority the BOB takes cognizance of the amount of appropriated funds approved by Congress. A certain percentage of these funds is considered to be representative of the dollar value of sales which the stock fund will make to consumers. This relationship of procurement to sales is a factor which is considered essential to any working capital revolving fund.

b. The application of the apportionment process by the BOB to the Army Stock Fund is considered to be a control device utilized to preclude those overbuying actions which would ultimately jeopardize the integrity of the fund. While these restrictions may be necessary from a national point of view, some commodity managers feel that they prohibit the timeliness of procurement actions. Others feel that until the stock fund is entirely void of procurement restrictions it cannot properly be classified as a truly revolving fund. These same opponents of the apportionment process are of the opinion that both sales volume and the need for operating cash are two factors which sufficiently motivate stock fund managers to operate effectively and efficiently.

c. Theoretically, operations of a working capital fund should be able to continue as long as operating cash is available. Such is not the case with the AMC stock fund division, which is

subjected to the BOB apportionment process. In imposing the restriction, the BOB grants obligational authority on an annual basis. Oftentimes, the limitations are such that obligational authority approved for the procurement of a certain commodity cannot be used to procure another commodity without the expressed approval of the BOB. The Army Materiel Command must obtain BOB approval before it can transfer obligational authority between its subordinate commands. This lack of flexibility can cause a delay in the support of consumers whose operating programs indicate periodic changes in missions and/or priorities. Occasionally, the restriction can also prevent the commodity manager from taking advantage of low market prices, thus limiting the attainment of certain stock fund objectives.

102. Precautions

a. The stock fund manager is concerned with an inventory turnover rate which will satisfy customer demands and require a minimum of dollar investment. If inventories increase and sales decrease, more of the fund capitalization is tied up in inventory; consequently, less operating cash is available for the procurement of new supplies.

b. A commodity manager must constantly be aware of the rate at which he will "sell" stock fund items to customers and must concern himself with the processing of collections and accounts receivable. To be in a position to effect timely procurement actions, both the commodity manager and the Finance and Accounting Office (FAO) must coordinate to the extent of projecting the procurement to sales ratio. By such forecasts the FAO can estimate the rate at which stock fund cash will accumulate from sales and that point in time when accounts payable will become due. Occasionally, it will be necessary to accelerate the processing of accounts receivable in order to obtain cash necessary to liquidate accounts payable. Any failure to provide for an adequate amount of cash to be on hand when bills become due may force the commodity manager to stop all procurement actions.

c. To be efficient, a stock fund manager must be an excellent merchandiser. Timely reports and wise management methods may enable him to detect movement toward an unfavorable stock position. If he over-invests in the procurement

of slow-moving items, he may lack the cash to procure other items which customers currently need. Furthermore, items in long supply bear the risk of becoming surplus with consequent loss to the fund.

103. Problem of Resource Allocation

a. Scientifically based inventory control models are generally designed to optimize the total variable costs of operation at a specified level of performance. Implementation of an improved model (or an initial model where no scientific inventory control system previously existed) invariably results in a requirement for out-of-pocket costs. This situation arises from the fact that existing inventories are not in balance on the basis of the new criteria. Excesses of some stocks exist while others are in short supply. In this case, inventories must be brought into line by procuring those items below desired stockage levels while allowing normal demand to reduce long supply items to their new goals. Because of the revolving nature of the ASF, indicated procurements must frequently be delayed until other stocks have been issued. Unfortunately, it is often the case that items out of balance in the long side move slowly, thus delaying the buildup of additional stocks where shortages have been occurring and additional safety stocks are required.

b. Even in instances where an ASF account is solvent, BOB or DA may limit the obligational authority of an NICP and force a departure from the theoretically optimum stockage policy. For these above reasons, it is often necessary to modify economic inventory policies to fit existing requirements within available funding resources. Several approaches to the allocation of limited funds are in use and still others are in development.

104. Methods in Use

a. Through use of their ADP equipment, most NICP's can obtain a reasonably accurate statement of anticipated funding requirements based upon current asset status, historical demand data, and forecasted program change factors. Once determined, this desired budget can be compared with authorized obligational authority. Such comparisons normally reveal that the actual budget is less than the desired budget, and

the problem arises as to how to allocate available funds.

b. One approach to resource allocation might be to reduce procurement quantities of all stocked items by the same percentage that the desired budget exceeds the actual budget. Such a scheme would have the advantage of being simple to explain and implement, but it would not be mathematically sound. It would not take into consideration existing imbalances between stocked items, or the fact that service level percentages are not related linearly to inventory investment (fig. 6).

c. Another method used to reduce procurements when funds are constrained is to artificially inflate holding costs (e.g., from 17 to 45 percent). Such an adjustment may easily be incorporated into ADPS supply control studies. Increasing holding cost will reduce EOQ's but increase ordering frequency. In the short run, funding requirements will be decreased; but over a long period, total costs will be increased because the correct ratio of ordering costs to holding costs will have been misstated in the EOQ calculations. Through the use of this device, less procurement money will be required (PEMA and ASF) over short time intervals, but more operating money (OMA) will be needed to pay procurement salaries; and, in the long run, procurement funds may also be increased because of failure to take quantity discounts.

d. Many NICP's reduce fixed safety levels when faced by a budgetary problem. This again is an arbitrary method, but one whose impact in procurement quantities is clear-cut and immediate. Fixed safety level quantity rates (30 or 60 days' supply at average demand) do not provide a uniform measure of protection against stockouts because they do not reflect differences in the variability of demands and in the length of lead times. A reduction of fixed safety levels will result in a short-term reduction of need for procurement funds but should also be expected to result in a significant drop in service levels.

e. Perhaps the best present way of reflecting budgetary constraints into procurement quantities is to apply an arbitrary reduction factor on a selective basis. The factor used could be percentage of EOQ, an increased holding rate, a portion of the safety level, or a combination of

all these items. It should *not* be applied, however, across-the-board to all stocked items but, rather, only to those presently in a good inventory position. Candidates for reduction of replenishment buys will probably evidence one or more of the following characteristics:

- (1) No stockouts in the past 12 months.
- (2) A long *PROLT* with a variable safety level.
- (3) A short *PROLT* with a fixed safety level.
- (4) A large *PMRMO*.
- (5) An average quarterly demand with a downward trend.
- (6) A long supply pipeline.
- (7) Physical stockage at all storage echelons.

105. Developments

a. Present methods of reacting to budgetary constraints are, at best, suboptimum and/or often extremely time-consuming. In order to be able to approach more closely an optimum allocation of limited funding resources, it is necessary to know more about the operation of

the logistics system as a total system, to have more accurate and timely data on assets position and demand trends, and to develop a model(s) that will permit rapid solution of an allocation problem on ADP equipment.

b. Research is presently being conducted on requirement computations in the framework of budgetary constraints. It is not yet known if the model(s) being developed will be sufficiently generalized to permit widespread application without major modifications.

c. Simulation studies of the logistics system are being made which should make major contributions to the knowledge of how the system now responds to changes. A discussion of these studies is contained in chapter 14.

d. There is little doubt that it will be possible to make more optimum use of limited resources in the future. In the meantime, supply management personnel should be cognizant of the shortcomings of their present allocation techniques and should recognize the need for continued improvement in both planning and methodology.

Section VI. OTHER COST CONSIDERATIONS

106. General

As pointed out in paragraphs 78 through 81, a consideration of costs enters into almost all supply management decisions. The costs of ordering and holding inventory have been discussed as have certain budgetary constraints and out-of-stock costs. This section addresses other cost elements that generally play a less significant—but still important—role in the decision-making process.

107. Lead Time Costs

a. The investment in inventory is directly affected by the length of the procurement lead time whenever protection against stockouts is provided by variable safety levels (*VSL*). A reduction in *PROLT* results in a reduction in *VSL*. The size of the *VSL* can be shown to vary as the square root of the *PROLT*.

b. The variable safety level quantity is determined as a function of the desired service level (percent protection against stockouts), the variability of demand (as measured by the standard

deviation, σ), and the length of the time interval during which protection is required (*PROLT*). The effect of these parameters on the *VSL* quantity can best be illustrated by a simple example (refer to chapter 9 for a more thorough discussion of *VSL*):

- (1) Data and Assumptions
 - (a) Demand distribution is assumed to be normal.
 - (b) $PROLT_1$ = four months; $PROLT_2$ = eight months.
 - (c) Standard deviation of monthly demand = 5 units (i.e., 84 percent of the months will have a demand less than the average value +5 units; 97.7 percent of the months, a demand less than the average value +10 units; and 99 percent of the months, a demand less than the average value +15 units).
 - (d) Desired protection is a 97.7 percent chance against stockouts (i.e., two standard deviations of protection).

- (2) *VSL* Determination for Case I
 $VSL_1 = (\text{level of protection}) (\sigma, \text{monthly basis})$

$$(\sqrt{PROLT_1 \text{ in months}})$$

$$VSL_1 = (2) (5) (\sqrt{4}) = 20 \text{ units.}$$

- (3) *VSL* Determination for Case 2

$$VSL_2 = (2) (5) (\sqrt{8}) = 28 \text{ units.}$$

- (4) Ratio of VSL_1 to VSL_2

$$\frac{VSL_1}{VSL_2} = \frac{\sqrt{4}}{\sqrt{8}} = \frac{1}{\sqrt{2}}$$

c. It is shown above that a reduction in *PROLT* will permit a reduction in *VSL* quantities. The relationship is a function of the square root of lead time rather than a linear one. While savings effected through the reduction of one or more of the elements of procurement lead time (administrative lead time, production lead time, and delivery lead time) may appear modest for an individual stocked item, they can be significant if many stocked items are involved. Supply management personnel should strive constantly for reductions in *PROLT* and should insure that values of *PROLT* used in supply control studies are accurate and up-to-date.

108. Management/Investment Cost Trade-Offs

a. It has been observed that the bulk of the supply management workload at the NICP arises from a small fraction of the items controlled that are temporarily out-of-stock or in a near critical asset condition. In other words, a great deal of time is spent putting out fires while items under control tend to remain under control with expenditure of only modest effort.

b. Stockage performance can be improved by developing better control systems or by providing more safety stocks through a greater investment in inventory. The former course of action is

receiving attention, and the latter is often impractical because of funding constraints. It should be recognized, however, that a relationship does exist between the cost of supply management and the cost of investment in inventory.

109. Procurement Cost Trade-Offs

When and how much to buy are decisions generally made by the head of an NICP. The details of contracting are then normally delegated to the procurement activity. It has been shown in this and earlier chapters, however, that decisions which can have a significant effect on the cost of the supply system (e.g., *PROLT*, quantity discounts) will be made subsequent to the preparation of a procurement directive. For this reason, it is extremely important that close and continuing relationships be maintained between supply control and procurement activities.

110. Total System Context

a. Operations research analysts often use the term suboptimization to mean that a solution was based on achieving the optimum results in only part of a system. Often, what is best for an element of a system would not be considered optimal in the context of the entire system. For example, a component design that provides the best operating characteristics may not prove to be the most reliable or may be out of line in terms of cost.

b. The Army's logistics system is composed of many functions besides supply control. It is more and more important that supply control decisions reflect a consideration of the total system. Models and techniques are being developed that will make this task easier in the future. In the meantime, the systems approach will be enhanced if each decision-maker stretches his horizons to include consideration of the cost and performance objectives of at least the next higher organizational entity.

CHAPTER 8

THE ECONOMIC ORDER QUANTITY

Section I. INTRODUCTION

111. General

a. It has been stated previously that the two basic inventory control questions are: "when to buy?" and "how much to buy?" The solution to the second question rests with the determination of an optimum order size, or economic order quantity (EOQ).

b. An order quantity, in this context, refers to the number of units procured from a vendor in a single order. This quantity may also be expressed in terms of time (e.g., six-months' supply) if the average demand is known. An economic order quantity is an order quantity which minimizes the total variable cost (TVC) function.

c. In the simple case, the total variable cost of maintaining inventories is considered to consist of two elements—the ordering cost and the holding cost. If an item is ordered in large quantities, it will be ordered infrequently and the annual cost of ordering will be small. Conversely, if each order represents many months of supply at average usage rates, the average operating level of stock in inventory will be high and holding costs proportionately high (fig. 24). Ordering and holding costs are, therefore, opposing costs, and a solution that reduces one increases the other.

d. The EOQ can be determined through a consideration of both ordering and holding costs with solution of a mathematical expression which reflects their relative importance. This point is shown graphically in figure 26.

The upper curve, 1, figure 26, depicts how annual ordering costs fall off exponentially as order quantity is increased. The middle graph, 2, figure 26, portrays how holding costs increase linearly with order quantity. Finally, the lower curve, 3, figure 26, shows how the total variable

cost, the sum of 1 and 2, figure 26, falls to a minimum between points (A) and (B) and then increases. It should also be noted that the total cost curve is relatively flat near the minimum and that little difference in total annual cost would be observed if the selected order quantity were greater than at point (A), but less than that at point (B).

e. It should be clearly understood that the ensuing discussion only refers to nonrepairable items. Discussion of repairables is deferred until chapter 11.

112. Scope of Application of the EOQ

a. To describe completely the application of the EOQ to inventory management, it is helpful to begin with the simplest case and proceed forward to more complex, "real-life" situations. The simple case described in paragraphs 113 through 117 is discussed only to provide an understanding of the need for more complex procedures. The many restricting assumptions stated make this need apparent.

b. In paragraphs 118 through 124 more complex procedures are developed by relaxing some of the restrictions stated in paragraphs 113 through 117. It is almost axiomatic that the more inclusive the procedures, the more complex they become. However, a certain degree of complexity must be tolerated if the "real-life" situation is to be adequately described.

c. It is important to note that procurement on the basis of EOQ's does not necessarily result in large order sizes. In many instances (e.g., high unit price items) EOQ's result in smaller order sizes than would result from a fixed reorder cycle policy.

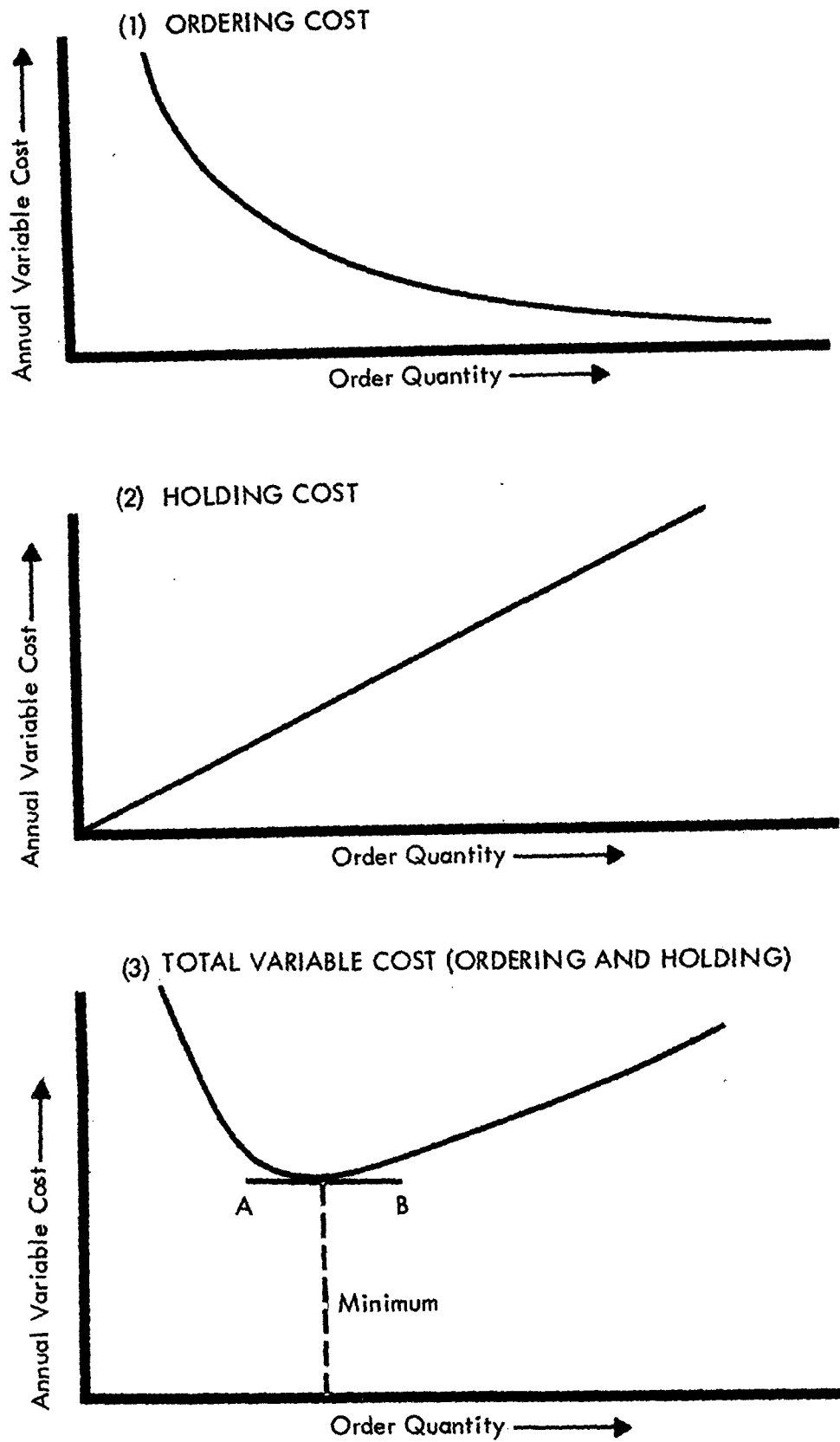


Figure 26. Variation in total annual variable cost of managing inventory versus order quantity.

Section II. THE SIMPLE CASE

113. Assumptions

a. Several assumptions are inherent in the development of the basic formula for an *EOQ*. These assumptions are as follows:

(1) Holding cost is made up of at least the following elements:

- (a) Losses in storage
- (b) Deterioration
- (c) Obsolescence
- (d) Maintenance in storage
- (e) Interest on funds invested in inventory. Other holding cost elements may be considered if the particular class of items for which an *EOQ* is being computed warrants their consideration. It is important to note that only the *variable* portions of these costs are considered in the calculation of an *EOQ*, that is, only costs which can be directly associated with the number of units held in stock. Any *fixed* costs which remain the same regardless of the number of units held in stock cannot be reduced by holding fewer units, and therefore are not considered in the computation of *EOQ*.

(2) Ordering is made up of at least the following cost elements:

- (a) Requirements review.
- (b) Contract placement and administration including inspection and acceptance.
- (c) Applicable portions of stock control and financial control activities.
- (d) Preparation, recording and submission of requirements requisitions and purchase requests.
- (e) Control and documentation efforts incident to shipment and receipt. Again, only the variable portion of procurement costs is of concern for this development (i.e., those procurement costs which increase with the number of procurement actions).

b. The most significant costs affecting the purchasing decision are cost to hold and cost to procure.

c. The marginal cost of an additional order is constant.

d. The marginal cost of carrying an additional item of inventory is constant.

e. The entire order arrives at one time (no partial shipments).

f. Demand is known and constant.

g. The marginal cost of an additional unit in a single purchase is constant—that is, there are no quantity discounts.

h. The purchasing decisions made for one item have no effect on the purchasing decisions for other items.

i. Stockouts or shortages are assumed not to occur.

j. Lead time is constant.

114. Derivation of *EOQ*

a. The simple inventory case described by the preceding assumptions can be graphically represented by the classical sawtooth curve shown in figure 27.

Assume, for purposes of this example, that the total planning period, T , is one year. A total requirement, Y , is determined for that planning period based on historical demand or based on engineering estimates for new items in the system. To satisfy requirements during time period T , a total of N orders is required, each consisting of Q units. Therefore, the annual order frequency, N , is simply

$$N = \frac{Y}{Q} \begin{matrix} \text{(total annual requirement)} \\ \text{(order quantity)} \end{matrix}$$

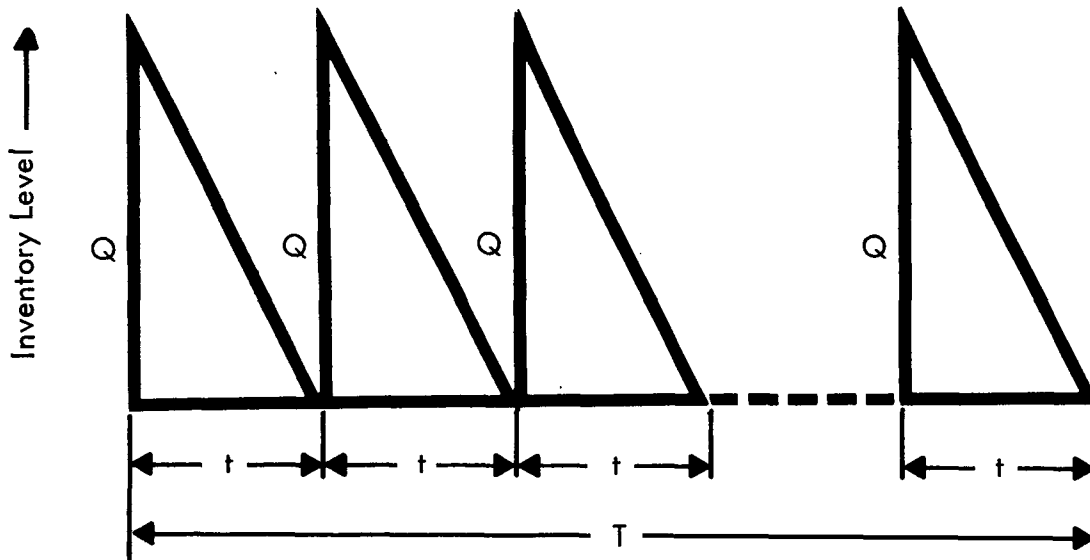
b. For the simple case, Q is constant throughout the total planning period. (For more complicated cases which are discussed later, Q can have a different value for each order cycle.) Associated with Q is a reorder cycle time, t , which is

$$t = \frac{T}{N} = \frac{T}{Y/Q} = \frac{TQ}{Y}$$

If the interval t begins with Q units in stock and ends with none, then

$$\frac{Q}{2} = \text{average inventory during } t$$

c. Ordering cost is the variable cost of placing an order, a cost which is assumed to be independent of the size of the order (no quantity discounts). If C is the cost of placing a single procurement order in dollars and N is the number



T = Total Planning Period (One Year)

t = Reorder Cycle Time

Q = Order Quantity

N = Number of Orders During Time T (Annual Order Frequency)

Y = NQ = Total Requirement for the Period (Annual Yearly Demand)

Figure 27. Simple case—inventory vs time.

of orders placed each year, the annual variable ordering cost is simply $C \times N$. While correct, this form of the ordering cost expression is not convenient when the problem is one of determining an economic order quantity. Recall that $N = \frac{Y}{Q}$. Substituting $\frac{Y}{Q}$ for N , we obtain the

following expression for ordering costs:

$$\text{Annual Variable Ordering Cost} = \frac{C(\$) \cdot Y(\text{units})}{Q(\text{units})}$$

d. Holding cost is the cost of physically storing the inventory plus the cost of the capital required for inventory investment. If H is the cost of holding inventory expressed as a percentage of the value of the inventory, U is the unit cost of an individual stock item, and $\frac{Q}{2}$ is the average

operating level of inventory on hand (assuming constant demand), then:

Annual Variable Holding Cost

$$= \frac{U(\$/\text{unit}) \times H(\%) \times Q(\text{units})}{2}$$

e. The total annual variable cost (TVC) of a simple inventory model is the sum of the two above costs, or

$$TVC = \frac{CY}{Q} + \frac{UHQ}{2}$$

f. The *EOQ* can be derived from the above equation by solving for a least cost solution either algebraically, graphically, or by the use of calculus. A graphical solution is shown in figure 28. Note that the minimum point of the total cost curve occurs just above the intersection of the ordering cost and holding cost curves. It is always true that the minimum total variable cost is obtained when the ordering and holding costs are equal. This fact, proven graphically, can be used to solve the *TVC* expression algebraically for the *EOQ*:

- (1) Set the holding cost equal to the ordering cost

$$\frac{UHQ}{2} = \frac{CY}{Q}$$

- (2) Multiply both sides by Q

$$\frac{UHQ^2}{2} = CY$$

- (3) Divide both sides by $\frac{UH}{2}$:

$$Q^2 = \frac{2CY}{UH}$$

- (4) Take the square root of each side:

$$Q = \sqrt{\frac{2CY}{UH}} = EOQ$$

This is the formula for the minimum cost value of Q , the economic order quantity. Inspection of this expression reveals that the EOQ is related to ordering and holding costs on a square root basis, that it varies directly with the elements of ordering costs, and indirectly with the elements of holding cost. Also, through further algebraic manipulation of the TVC formula, an expression can then be written for the total variable cost associated with the EOQ , Q_o , which is

$$TVC_o = \sqrt{2YUHC}$$

g. The use of these formulations to determine an economic order quantity can best be illustrated with an example.

(1) Assump-	Annual Re-	= $Y = 100$ units
tions:	quirement	
	Cost per	= $C = \$200$
	order	
	Unit Cost	= $U = \$10$
	Cost of	= $H = 20$ per-
	Holding	cent
	Inventory	

- (2) Arithmetical Solution

$$EOQ = Q_o = \sqrt{\frac{2CY}{UH}}$$

$$Q_o = \sqrt{\frac{2 \cdot 200 \cdot 100}{10 \cdot (0.20)}}$$

$$Q_o = \sqrt{20,000}$$

$Q_o = 141$ units (i.e., purchase 17 months' supply)

$$\begin{aligned} TVC_o &= \sqrt{2YUHC} \\ &= \sqrt{2 \cdot 100 \cdot 10 \cdot (0.20) \cdot 200} \\ &= \sqrt{80,000} = \$282 \end{aligned}$$

Table 15. Tabularized Costs

Tabularized Costs

Order Quantity Q (units)	Order Frequency N (years)	Ordering Cost $\frac{CY}{Q}$ (\$)	Holding Cost $\frac{UHQ}{2}$ (\$)	Total Variable Cost TVC (\$)
50	2.0	400	50	450
100	1.0	200	100	300
141	0.71	141	141	282
150	0.67	133	150	283
200	0.50	100	200	300
300	0.33	67	300	367

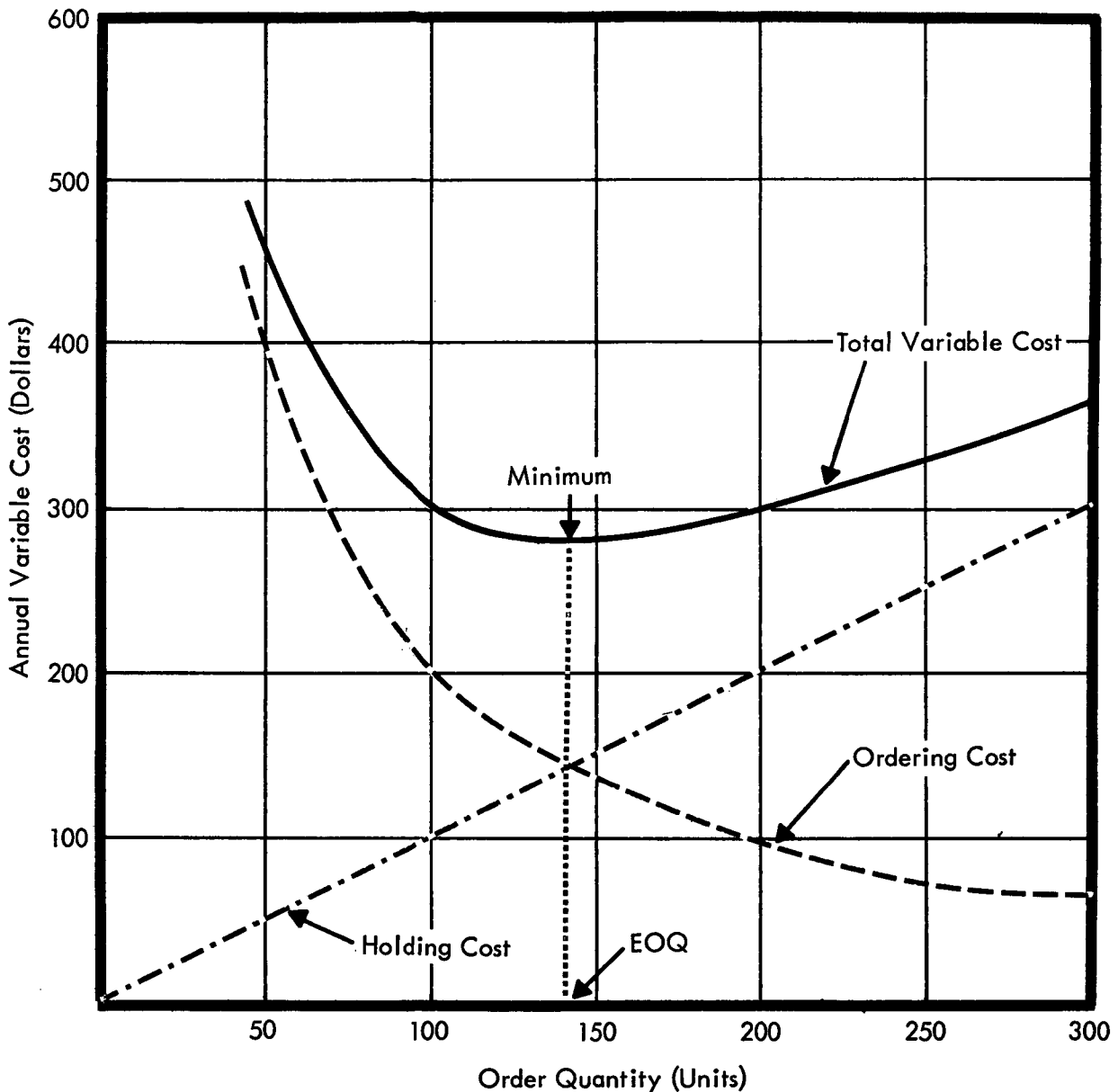


Figure 28. Graphical solution of EOQ problem.

- (3) The graphical solution of this problem is shown in figure 28. Inspection of this graph or of table 15 reveals that the minimum cost solution occurs when the annual cost of ordering is equal to the annual cost of holding and that differences in total variable costs are small in a relatively wide range about the minimum cost point.

115. Effect of Over- or Under-Stating Cost Elements in EOQ Equation

a. It has been mentioned on several occasions that the total variable costs of a simple inventory model do not vary greatly in a moderate range about the optimum order quantity point. This fact has been implied by the shape of the total variable cost curve and explained, in part, as being a function of the square root relationship

of the equation. The magnitude of a loss which might result from improper estimates of ordering or holding costs is illustrated in the two examples discussed below.

b. The cost of ordering is known to vary with the type of procurement action which, in turn, is a function of the dollar magnitude of the order quantity. In this example, assume that when the procurement quantity is less than \$2,500 the cost of ordering is \$150, but when the procurement quantity is greater than \$2,500 the cost of ordering is \$600. In this problem, a loss occurs because the *EOQ* is calculated on the basis of an ordering cost of \$150; but, when the *PD* is forwarded to the procurement activity for action, an actual ordering cost of \$600 is incurred.

(1) Data

Unit Cost	= $U = \$25$
Holding Cost	= $H = 0.20$
Ordering Cost	= $C = \$150$ (estimated) \$600 (actual)
Annual Requirement	= $Y = 160$ units

(2) Directed *EOQ* (Q') based on expected C of \$150

$$Q' = \sqrt{\frac{2CY}{UH}} = \sqrt{\frac{2 \cdot 150 \cdot 160}{25(0.20)}} = 96.$$

(3) Optimum *EOQ* (Q_o) if actual C of \$600 had been used

$$Q_o = \sqrt{\frac{2 \cdot 600 \cdot 160}{25(0.20)}} = 196.$$

(4) Actual total annual variable cost based on actual C and directed order quantity

$$TVC_A = \frac{CY}{Q'} + \frac{UHQ'}{2}$$

$$TVC_A = \frac{600 \cdot 160}{98} + \frac{25(0.20)98}{2} = \$1,225.$$

(5) Optimum *TVC* if order quantity had been calculated on a basis of actual C

$$TVC_o = \frac{C \cdot Y}{Q_o} + \frac{UHQ_o}{2}$$

$$TVC_o = \frac{600 \cdot 160}{196} + \frac{25(0.20)196}{2} = \$980.$$

(6) Ratios

(a) $\frac{\text{Estimated } C}{\text{Actual } C} = \frac{150}{600} = \frac{1}{4} = 0.25$

(b) $\frac{\text{Calculated } EOQ}{\text{Optimum } EOQ} = \frac{98}{196} = \frac{1}{2} = 0.50$

(c) $\frac{\text{Actual } TVC}{\text{Optimum } TVC} = \frac{1225}{980} = 1.25$

Note. In this example an error of .25 in ordering cost affected the *EOQ* by a factor of $\frac{1}{2}$ (square root of $\frac{1}{4}$) but affected total variable cost by only 25 percent.

c. This second example illustrates the effect of underestimating holding cost by a factor of two. This could easily occur due to an unforeseen "surprise obsolescence."

(1) Data

Unit Cost	= $U = \$25$
Holding Cost	= $H = 0.20$ (estimated) 0.40 (actual)
Ordering Cost	= $C = 150$
Annual Requirement	= $Y = 125$

(2) Directed *EOQ* (Q') based on estimated H of 20 percent

$$Q' = \sqrt{\frac{2CY}{UH}} = \sqrt{\frac{2 \cdot 200 \cdot 125}{25(0.20)}} = 100.$$

(3) Optimum *EOQ* (Q_o) if actual H of 40 percent had been used

$$Q_o = \sqrt{\frac{2 \cdot 200 \cdot 125}{25(0.40)}} = 71.$$

(4) Actual total annual variable cost based on actual H and directed order quantity

$$TVC_A = \frac{CY}{Q'} + \frac{UH \cdot Q'}{2}$$

$$TVC_A = \frac{200 \cdot 125}{100} + \frac{25(0.40)100}{2} = \$750.$$

(5) Optimum *TVC* if order quantity had been calculated on basis of actual H

$$TVC_o = \frac{200 \cdot 125}{71} + \frac{25(0.40)71}{2} = \$707.$$

(6) Ratios

(a) $\frac{\text{Estimated } H}{\text{Actual } H} = \frac{0.20}{0.40} = \frac{1}{2} = 0.50$

(b) $\frac{\text{Calculated } EOQ}{\text{Optimum } EOQ} = \frac{100}{71} = \sqrt{2} \text{ or } 1.41$

(c) $\frac{\text{Actual } TVC}{\text{Optimum } TVC} = \frac{750}{707} = 1.06.$

Note. In this example an error of .50 in holding cost affected the *EOQ* by a factor of the square root of 2 but affected total variable cost by only six percent.

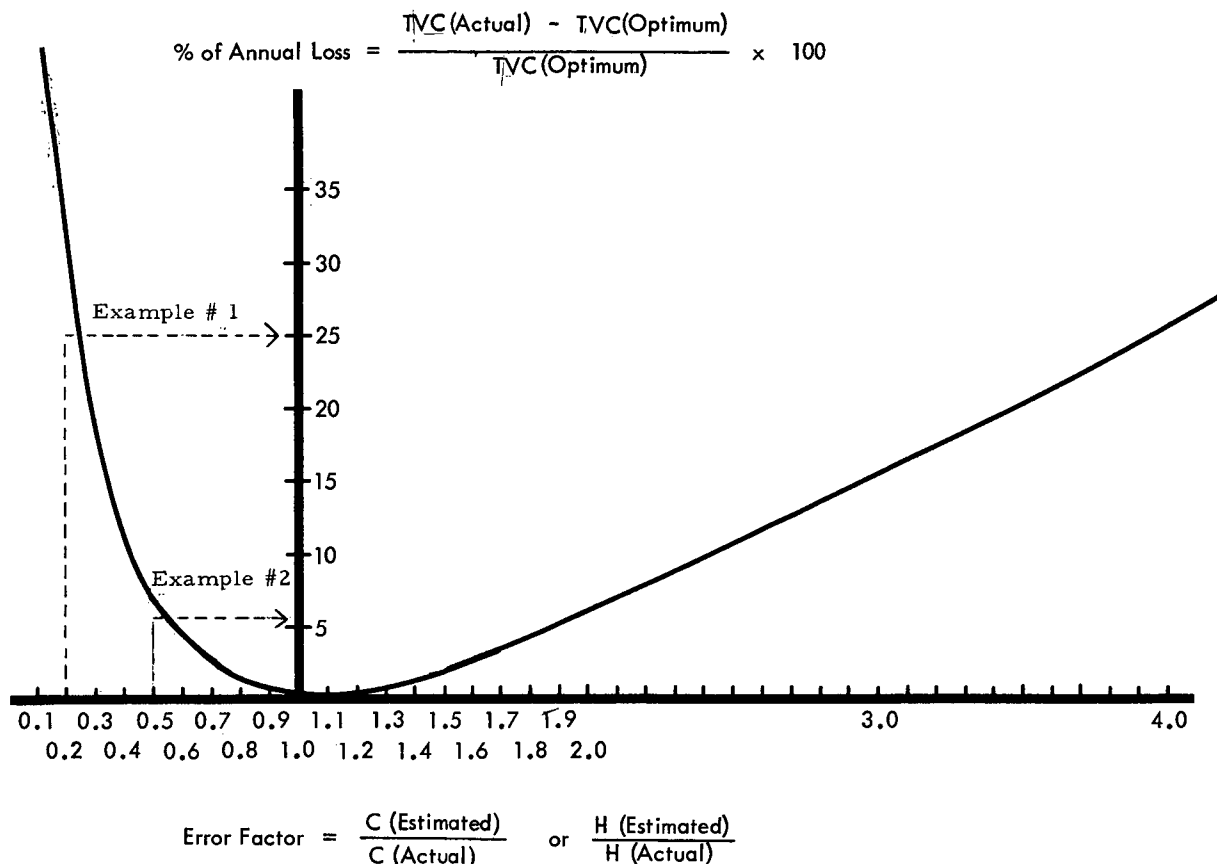


Figure 29. Potential loss resulting from error in estimate of ordering or holding cost.

d. This relationship between errors in the estimate of ordering and holding cost and total annual variable cost is shown graphically in figure 29. The size of the estimate error, expressed as a ratio, is represented along the horizontal axis of the graph. The vertical axis indicates the relative loss resulting from the use of an improper estimate. This loss is expressed as a percentage of the optimum annual total variable cost.

116. Practical Considerations in the Use of Economic Order Quantities

a. The equations for calculating economic order quantities and total annual variable costs are mathematically exact for the simple inventory model which assumes constant demand rates and ignores safety levels and out-of-stock costs. In actual applications, when accurate data on ordering and holding costs are available, the use of these equations provides a good basis for the derivation of an optimum theoretical procurement

quantity. However, there remains a requirement for subjective judgment in extreme cases of very large or very small buys (in terms of months of average usage).

b. When unit price and demand rate are low or when ordering cost is high, the calculated *EOQ* may represent 5 or more years' supply at average usage rates. Such a purchase quantity may be theoretically correct based on present data. But, because of a practical inability to look this far into the future with any real confidence (variations in demand rate, unit price, obsolescence, preservation in storage), *EOQ*'s that represent more than 5 years' supply should be severely questioned and probably reduced. Such reductions may be made arbitrarily by incorporating maximum buy quantities into NICP LDV item standard operating procedures or may be based on a second analysis which makes use of a higher holding cost to reflect the uncertainties of the future.

c. Conversely, high unit prices combined with high demand rates will result in *EOQ*'s so

small that purchasing frequencies in excess of once per month would be required. These are normally HDV items which are procured on a basis of advertising and competitive bids. To avoid overloading government purchasing offices, and to reflect the prior observation that *EOQ* calculations are less meaningful in extreme cases, most NICP's establish a minimum reorder cycle which is usually three months. This somewhat arbitrary action on the part of supply managers implies that excessively small *EOQ*'s result and that holding costs are much lower than 17 percent. Such an assumption is probably valid. For example, frequently procured items have high turnover rates which suggest that deterioration and obsolescence elements are much lower than the 10 percent (five percent each) allowance normally provided. Also, a detailed analysis of federal accounts on a cash flow basis would be required to substantiate the reasonableness of a four percent interest rate for items procured several times each year. Therefore, for many HDV items, a holding cost of four to eight percent may be accurate, thus justifying a doubling of an *EOQ* calculated on the basis of a 17 percent holding cost.

d. Heads of NICP's, by USAMC delegation, may now extend high dollar item *EOQ*'s to 4 to 12 months, with phased deliveries, no increase in investment, but a savings in procurement. Arbitrary across the board cut of some fixed percentage may result in missing out on quantity discounts (discussed later in this chapter), and in missing the opportunity for continuous production contracts.

117. Aids to Calculation of *EOQ*'s

a. As discussed in chapter 10, ADP equipment is easily programed to perform routine calculations and the use of such equipment for the determination of economic order quantities is encouraged. All NICP's now calculate *EOQ*'s for LDV items with ADPS and many perform similar operations for MDV and HDV items as an input to manual supply control studies. In this manner, the need for clerical computation of *EOQ*'s has been practically eliminated.

b. On the other hand, tables may be constructed which relate the size of the economic procurement directive (in dollars) to forecasted annual dollar demand wherever manual cal-

culations are required. These tables are based on a simple rearrangement of the basic *EOQ* formula.

$$(1) Q_o = EOQ = \sqrt{\frac{2CY}{UH}}$$

(2) Multiplying both sides by unit cost, *U*

$$Q_o U = U \sqrt{\frac{2CY}{UH}} = \sqrt{\frac{2CYU}{H}}$$

(3) Since $Q_o U$ is the value of the purchase quantity, *Q* (in dollars), and *YU* is the annual dollar demand, *AYD* (in dollars), this expression can be written

$$Q \text{ (in dollars)} = \sqrt{\frac{2C \cdot AYD \text{ (in dollars)}}{H}}$$

(4) Knowing the ordering cost, *C*, and the holding cost, *H*, various values of annual dollar demand, *AYD*, can be inserted and the formula solved for *Q*.

Data obtained from solution of the above equation may be summarized in a table for easy reference. A supply analyst can then enter the table with annual dollar demand and obtain the appropriate purchase quantity in dollars. This figure may then be simply converted to the number of units through division by the unit price. The relative insensitivity of total variable annual costs to small differences in *EOQ* makes it unnecessary to construct a table with more than about 50 entries, nor to interpolate between these entries.

c. With only a little more effort than that involved in the construction of the above table, more precise estimates of *EOQ*'s can be obtained through the use of a nomograph. The method of constructing a nomograph is beyond the scope of this manual, but is a simple task for a mathematician. A separate nomograph must be constructed for each pertinent value of holding or ordering cost (this is also true in the case of the table discussed above). Once the nomograph is available, a supply analyst can determine the *EOQ* from the nomograph by knowing the annual requirement (units) and unit cost (\$) and using a straightedge to read off *EOQ*. Figure 30 illustrates a typical order quantity nomograph. In the example shown here, the *EOQ* for an item which costs \$30 and has a forecasted annual requirement of 1,000 units is determined to be 400 units.

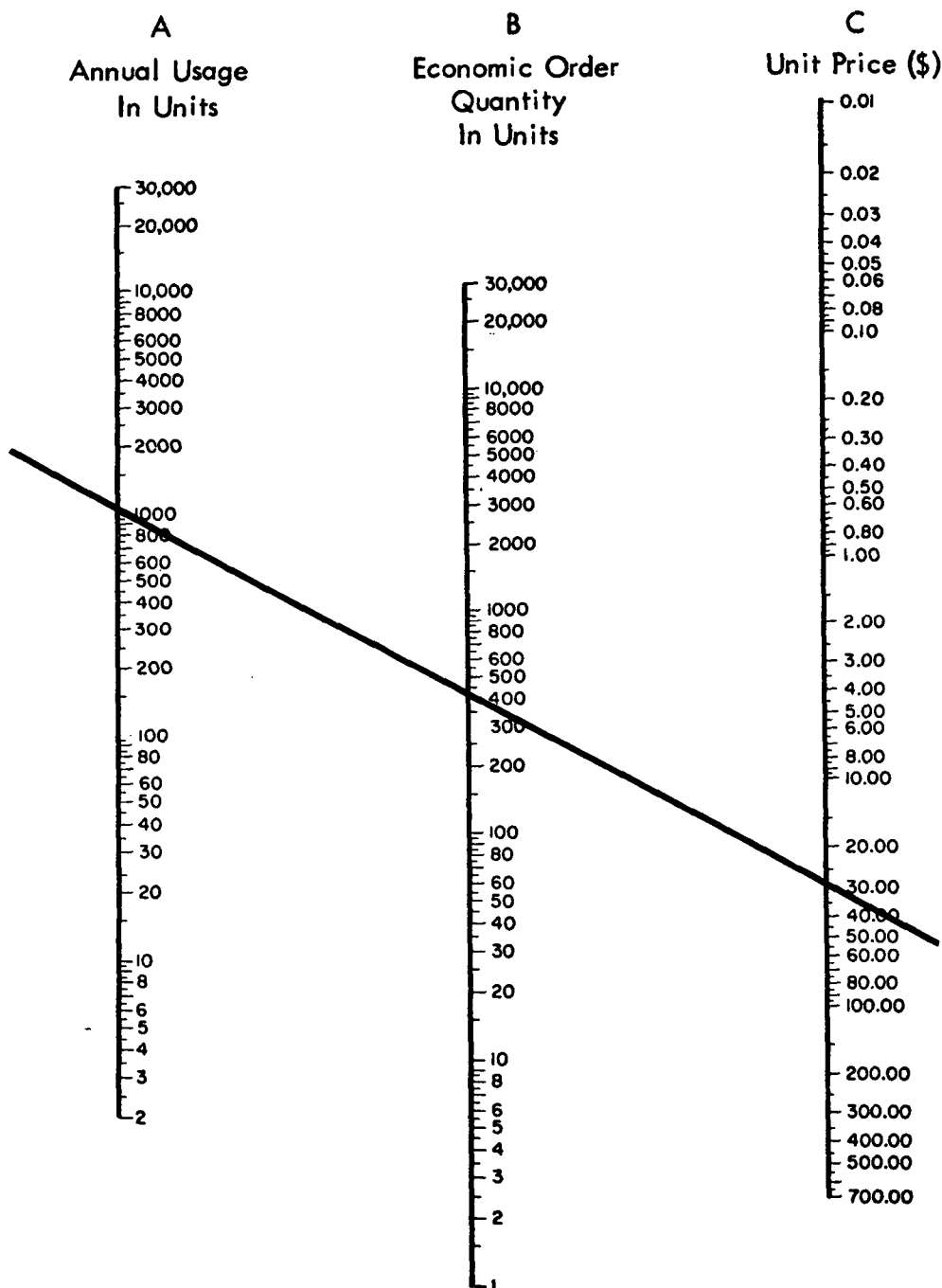


Figure 30. Typical EOQ monograph.

Section III. ECONOMIC ORDER QUANTITIES WITH OUT-OF-STOCK COSTS

118. Introduction

Out-of-stock costs are all of the costs associated with being out-of-stock when a requisition is received. These costs were discussed in paragraphs 106 through 110. They are difficult to determine in the Army situation. For purposes of the mathematical example below, it is assumed that the cost of being out-of-stock can be expressed accurately on a per unit, and per unit of time basis.

119. Assumptions and Derivation

a. The assumptions inherent in this section are the same as those stated in paragraph 113 except as indicated in *i*, as stockouts will be allowed to occur in this example.

b. The out-of-stock situation can be represented graphically as shown in figure 31. In the figure, t_1 is the time during which inventory is available, t_2 is the out-of-stock time, and S is the inventory level at the beginning of each interval.

c. Using the simple geometric relationship of similar triangles, the following equations are developed

$$t_1 = \frac{S}{Q}t$$

$$t_2 = \frac{Q-S}{Q}t$$

d. The average number of units held in inventory during t_1 is $\frac{S}{2}$. Therefore

$$\frac{S}{2}HU t_1 = \text{holding cost during } t_1.$$

e. Similarly, the average number of units short during t_2 is $\frac{Q-S}{2}$. Therefore

$$\frac{Q-S}{2}C_s t_2 = \text{the average out-of-stock cost during } t_2$$

where

C_s = the cost of being out-of-stock one unit of inventory for a unit of time.

f. Therefore, the total variable cost for N orders is

$$TVC = \text{Annual Cost to Hold} + \text{Annual Cost to Procure} + \text{Annual Out-of-Stock Cost.}$$

g. By taking the first derivative of TVC with respect to Q , setting it equal to zero, and solving for Q , the following expression for Q_o results

$$Q_o = \sqrt{\frac{2CY}{UH}} \cdot \sqrt{\frac{UH+C_s}{C_s}}$$

again, Q_o is the EOQ for this case. The TVC value associated with Q_o is simply

$$TVC_o = \sqrt{2YUHC} \cdot \sqrt{\frac{C_s}{UH+C_s}}$$

120. Illustrative Example of an EOQ Computation with Out-of-Stock Costs

a. Data

Cost per order = $C = \$200$

Annual requirement = $Y = 100$ units

Unit price = $U = \$10$

Holding cost rate = $H = 20$ percent

Unit stockout cost = $C_s = \$3/\text{unit}/\text{time unit}$

b. Computations

$$EOQ = \sqrt{\frac{2 \cdot 200 \cdot 100}{10(0.20)}} \cdot \sqrt{\frac{2+3}{3}}$$

$$EOQ = 141 (1.29) = 182 \text{ units}$$

$$TVC_o = \sqrt{2 \cdot 100(0.20)10 \cdot 200} \cdot \sqrt{\frac{3}{2+3}}$$

$$TVC_o = 282 (0.78) = \$220.$$

Similarly, the optimum values of S and N are

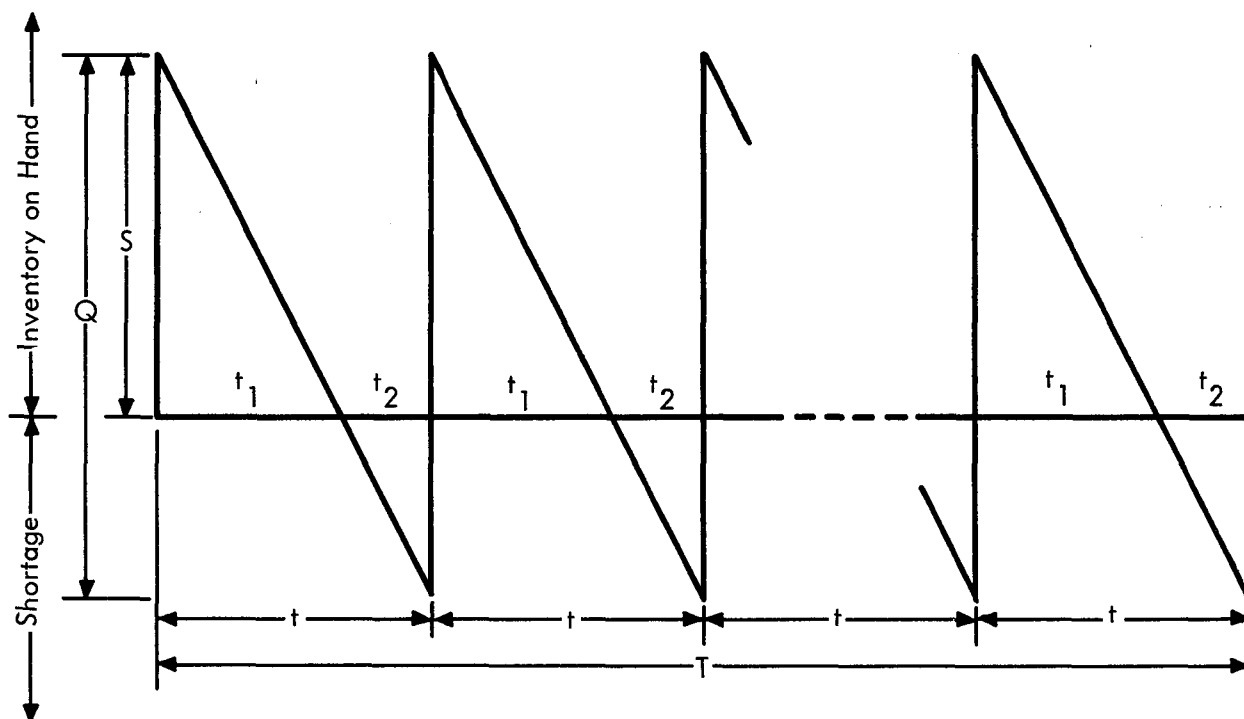
$$S_o = \sqrt{\frac{2CY}{UH}} \cdot \sqrt{\frac{C_s}{UH+C_s}}$$

$$N_o = \frac{Y}{Q_o}$$

$$S_o = \sqrt{\frac{2 \cdot 200 \cdot 100}{10(0.20)}} \cdot \sqrt{\frac{3}{2+3}} = 110 \text{ units}$$

$$N_o = \frac{100}{182} = 0.55 \text{ orders/year}$$

c. In the example shown, the item being managed was out-of-stock 40 percent of the time. This was a result of arbitrarily choosing values for holding cost and out-of-stock costs as 20 percent of inventory value and \$3/piece/time unit, respectively. In a more realistic situation the out-of-stock cost would probably be much higher relative to the holding cost, resulting in an out-of-stock position occurring only 5 percent or 1 percent of the time (i.e., 95 or 99 percent service level).



T = Total Planning Period (One Year)

t = Order Cycle Time

Q = Order Quantity

N = Number of Orders During Time T (Annual Order Frequency)

Y = NQ = Total Requirement for the Period (Annual Yearly Demand)

t_1 = $\frac{S}{Q} t$ = Time that Requisitions Can Be Satisfied

t_2 = $\frac{Q - S}{Q} t$ = Out-of-Stock Time

S = Inventory Level at the Beginning of Each Interval

Figure 31. With out-of-stock costs inventory level vs time.

Section IV. QUANTITY DISCOUNT MODEL

121. General

The inventory models considered so far do not take into account quantity discounts (or price breaks). To do so involves relaxing the assumption that the marginal cost of an additional unit in a single purchase is constant (para 113g).

122. Definition of Quantity Discount (Range Bidding)

a. A quantity discount or price break is a reduction in unit price given for all additional units ordered in a single order over a certain stated level. For example, a manufacturer might charge \$1/unit for the first 999 units, and \$.95/unit for an order of 1,000 to 1,999 units, and \$.90/unit for an order of 2,000 or more units. This would be a situation with two price breaks, one at 1,000 units, and a second at 2,000 units. If a buyer has decided upon an order quantity of 800 units, then he must weigh the additional cost of storing 200 extra units of inventory for a specified length of time against the savings obtained from the quantity discount.

b. While the supplier bases quantity discounts upon a consideration of setup costs which are normally discussed as an element of ordering costs, it can be shown that, once an order quantity has been selected, the holding cost curve is affected rather than the ordering cost curve.

123. Model with One Price Break

a. There are four possible situations for a model with one price break which is offered for a purchase quantity of B units.

First define:

U_1 = unit cost of purchases of less than B units.

U_2 = unit cost of purchases of equal to or greater than B units.

Q_1 = EOQ associated with U_1

Q_2 = EOQ associated with U_2

* TVC_1 = total variable cost associated with Q_1

* TVC_2 = total variable cost associated with Q_2

* TVC_B = total variable cost associated with B

b. Case 1, a, figure 32: $B < Q_1 < Q_2$, then

$$TVC_1 > TVC_B > TVC_2$$

and minimum cost purchase quantity = Q_2 .

c. Case 2, b, figure 32: $Q_1 < B < Q_2$, then

$$TVC_B > TVC_2$$

and minimum cost purchase quantity = Q_2 .

d. Case 3, c, figure 32: $Q_1 < Q_2 < B$, then

$$TVC_1 > TVC_B$$

and minimum cost purchase quantity = B .

e. Case 4, d, figure 32: $Q_1 < Q_2 < B$, then

$$TVC_B > TVC_1$$

and minimum cost purchase quantity = Q_1 .

f. In cases 1 and 2, TVC_1 , TVC_2 and TVC_B are uniquely defined by the conditions imposed on Q_1 , Q_2 and B . In cases 3 and 4 either $TVC_1 > TVC_B$ or $TVC_1 < TVC_B$. The optimal purchase quantity can take one of three values (Q_1 , Q_2 or B) depending on the conditions of the problem. The extension of this procedure follows for multiple price break models, but the computations become more involved as the number of price breaks increases.

124. Illustrative Example

a. Case 1, a, figure 32:

$$Q_1 = 200 \quad 150 < 200 < 224$$

$$Q_2 = 224$$

$$B = 150$$

$$TVC_1 = \$52,020 \quad \$52,020 > \$41,953 > \$41,800$$

$$TVC_2 = \$41,800$$

$$TVC_B = \$41,953$$

therefore minimum cost purchase quantity = 224 units.

b. Case 2, b, figure 32:

$$Q_1 = 200 \quad 200 < 210 < 224$$

$$Q_2 = 224$$

$$B = 210$$

$$TVC_B = \$41,810 \quad \$41,810 > \$41,800$$

$$TVC_2 = \$41,800$$

therefore minimum cost purchase quantity = 224 units.

c. Case 3, c, figure 32:

$$Q_1 = 200 \quad 200 < 224 < 300$$

$$Q_2 = 224$$

$$B = 300$$

$$TVC_1 = \$52,020 \quad \$52,020 > \$41,887$$

$$TVC_B = \$41,887$$

therefore minimum cost purchase quantity = 300 units.

d. Case 4, d, figure 32:

$$Q_1 = 200 \quad 200 < 224 < 400$$

*In the simple case, unit cost was constant, and the cost of the material did not enter into TVC since it was a fixed cost. With a price break, however the unit cost decreases at the price break, so the cost of material is variable and must be considered in computing TVC.

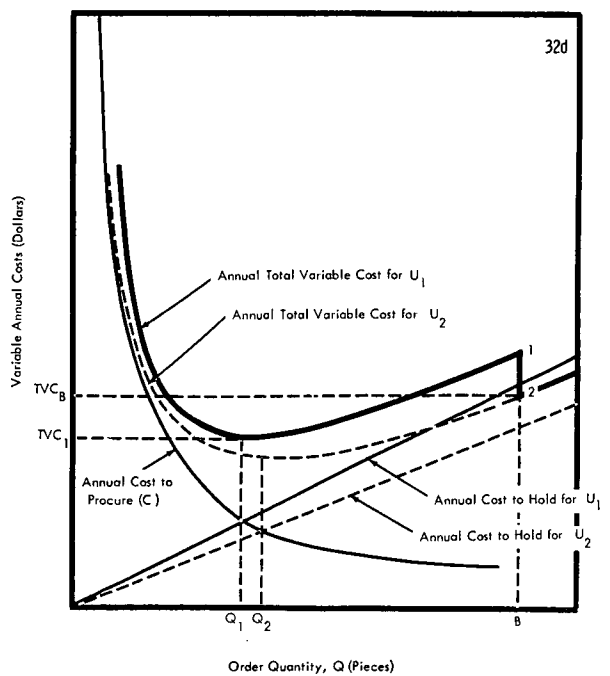
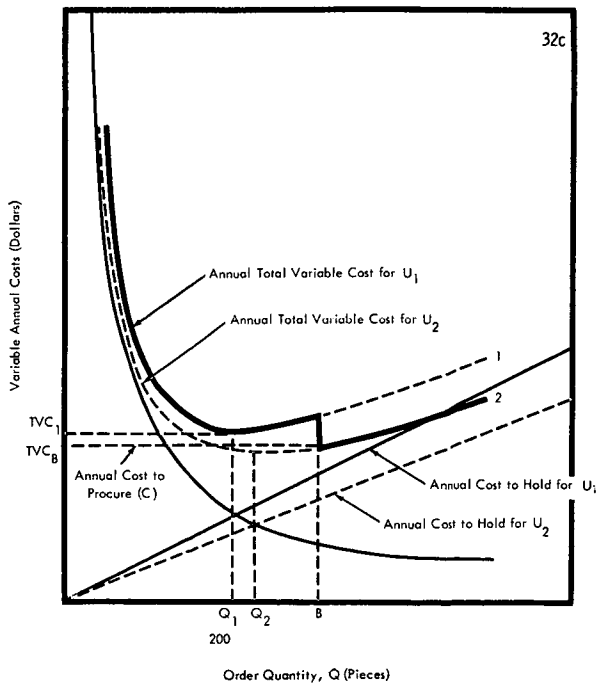
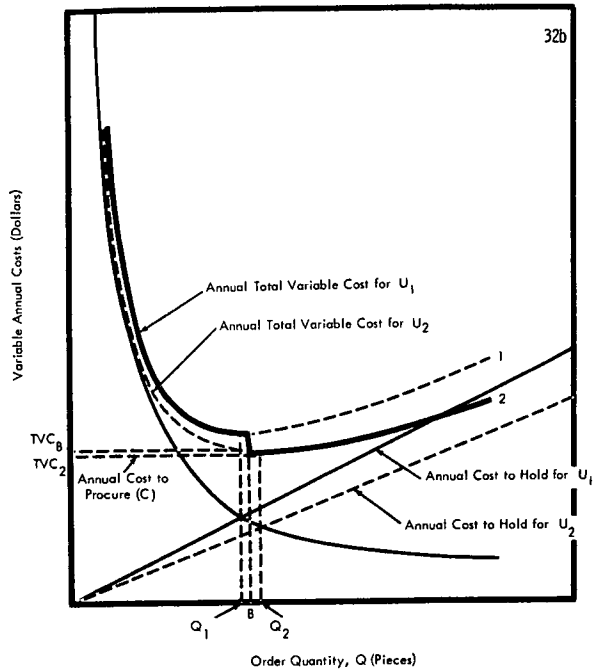
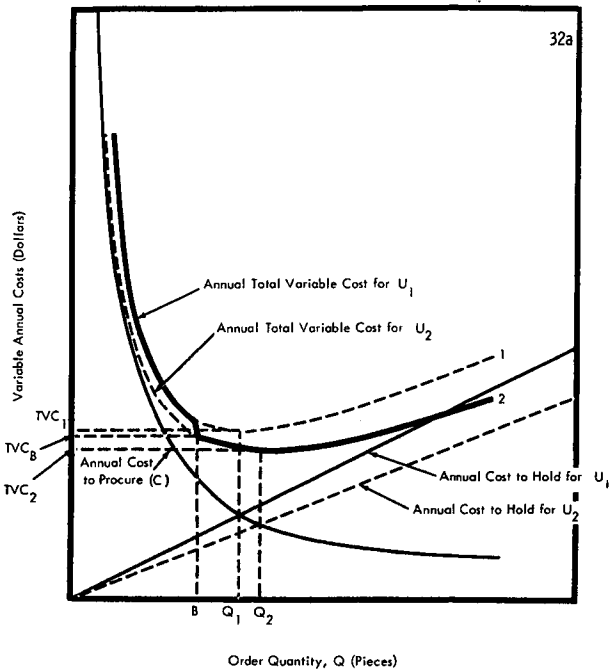


Figure 32. Quantity discount models.

$$Q_2 = 224$$

$$B = 400$$

$$TVC_B = \$52,087 \quad \$52,087 > \$52,020$$

$$TVC_1 = \$52,020$$

therefore minimum cost purchase quantity = 200 units.

e. The concept of quantity discounts can be used with the existing procedures as well as with some of the more advanced inventory models discussed in chapter 13.

Section V. MORE GENERAL MODELS

125. General

Three examples of *EOQ* models have been given thus far. The first was the simple case which included many restrictions. In paragraphs 118 through 124 the assumptions of no shortage and no quantity discounts were relaxed. If some of the other assumptions listed in paragraph 113 are relaxed, the problem becomes even more involved.

126. Generalization of the Model

a. If the following new assumptions are made, the effect on the inventory model sawtooth curve is quite dramatic.

- (1) Shortages are considered (a safety level is required to protect against them).
- (2) Demand is known, but not constant.
- (3) Order cycle time is not constant over the total planning period.

An additional assumption of variable order quantity could be introduced in place of assumption (3) above. In inventory modeling it is customary to either fix order quantity as $Q = RO - REOPT$ in which case assumption (3) above holds as shown in figure 33, or to fix review cycle,

in which case variable order quantities are possible. Chapter 17 includes a discussion of fixed review cycle models.

b. A further generalization of the model could include an unknown, variable rate of demand. In this instance, which is usually the case in Army inventory situations, a distribution of demand must be hypothesized on the basis of historical behavior of demand or on some other basis. Once this hypothesis has been made and tested, a probability can be associated with the occurrence of a demand at any point in time. Similarly, a probability can also be associated with the occurrence of a given order size. The concept of demand distributions is discussed in chapter 16, and the development of safety level quantities based upon the demand variability is treated next in chapter 9.

127. Summary

It is apparent from the foregoing discussion that a broad spectrum of models exists for the determination of *EOQ*'s. These models can then serve as a basis for inventory decisions. The degree of simplicity or complexity depends largely on the assumptions that can be made. The trade-offs in accuracy versus degree of complexity must be weighed in the selection of a proper model.

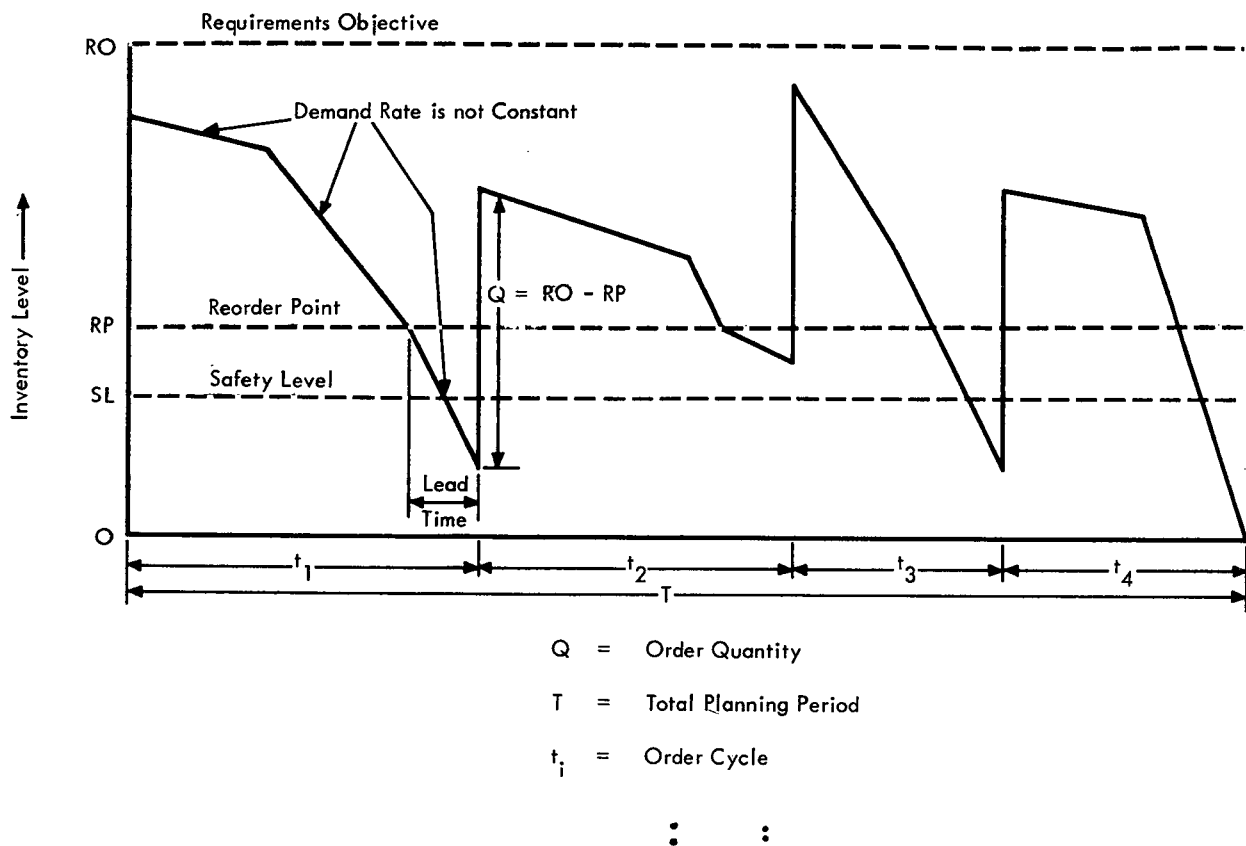


Figure 33. General inventory model—inventory level vs time.

CHAPTER 9

VARIABLE SAFETY LEVELS

Section I. SAFETY LEVELS

128. General

a. To protect against the occurrence of an out-of-stock position, a stockage level in excess of the reorder cycle level is created. This level is referred to as the safety level (SL). If the variability in item failure rates was the only consideration, safety levels could be predicted quite easily. However, variability in demand depends upon many other factors which occur at all levels of the supply system and which collectively affect wholesale requisitioning frequency. Consequently, the computation of a safety level which will insure a stated level of total system performance is much more complicated than a simple analysis of maintenance requirements. Further, it should be understood at the outset that safety levels are intended to protect against shortages resulting from random variation in item demand. They are *not* intended to protect against definite trends in average demand rates.

b. As was discussed in chapter 6, inventories are most vulnerable to stockout during the procurement lead time (PROLT). For this reason safety levels are normally established on the basis of expected variability in demand during the PROLT.

129. The Need for Variable Safety Levels

a. In the past, the Army treated demand as constant and established fixed safety levels of 30 days with authorization of 60 days for selected low dollar value items. However, it was determined that, to more closely represent the actual situation, the variability of demand had to be considered on an individual item basis. Hence, the need for variable safety levels arose.

b. Under the variable safety level concept, some measure of total system performance must be decided upon. The current measures of performance and the attributes of each are discussed in chapter 12. For illustrative purposes "item

availability" is used in this discussion. That is, the system has items available for shipment, or is "in" stock "X" percent of the time. The percentage denotes the level of protection that is afforded by the system.

c. A particular level of protection may be selected on the basis of dollar value, combat essentiality, and other criteria. If procurement lead time is considered to be constant, the parameters which determine a safety level are the length of the procurement lead time and the desired level of protection. For example, in the normal procedure, an EOQ is calculated which fixes the reorder cycle, the procurement lead time required for this order size is determined, desired level of protection is then selected (say, 95 percent), and finally, a safety level quantity is determined which provides this protection over the PROLT. However, whereas the safety level quantity provides protection for variability in demand over procurement lead time, it should be recognized that the safety level quantity should also be based on a consideration of the length of the reorder cycle.

d. It should be pointed out that, in a statistical sense, 100 percent protection is impossible to achieve. There is always a finite, though remote, possibility that an extremely large demand will occur during the procurement lead time which would exhaust the available inventory before a replenishment arrives. A larger and larger safety level increases the level of protection, but also increases procurement funding requirements and holding costs. The problem, then, is to determine a safety level on a basis which considers the trade-off between protection and cost.

e. When funds are limited, NICP's often reduce safety level quantities or convert from VSL's to fixed safety levels. Reduction of safety levels is a valid method of reacting to a budgetary

constraint. However, it should be recognized that when variable safety levels are used the reduced level of protection may be quantitatively measured, expressed as a percentage, and calculated in a computer. On the other hand, a single fixed safety level (say, 30 days) does not

provide a uniform level of protection among items, nor can the amount of protection be easily calculated. The use of VSL's, therefore, furnishes a more meaningful basis for reacting to budgetary constraints than do fixed safety levels.

Section II. THE STANDARD DEVIATION

130. General

In the past, forecasting procedures based on historical data have attempted to predict the average demand for a planning period. While this procedure is valuable, it does not go far enough. It has been found that random short-term fluctuations in demand contribute largely to the unpredictability of demand. These short-term fluctuations are generally larger for high demand items than for low demand items. The computation of average demand alone does not consider these fluctuations and therefore does not provide sufficient protection against the possibility of a stockout. In order to protect against these fluctuations, the "variance" of demand must be considered in addition to the average of mean demand.

131. Definition of Standard Deviation

a. The variance of demand, commonly denoted σ^2 measures the amount of variability inherent in a particular set of observations. The standard deviation of demand is simply the positive square root of the variance, or σ , and also is a measure of variability.

b. Knowing the average or mean demand, μ , the standard deviation, σ , and the type of distribution (ch 16), a probability can then be found for the occurrence of a particular demand.

132. Derivation of Standard Deviation

a. As will be discussed in chapter 16, an estimate of the mean can be found simply by adding up all of the observed values and dividing by the total number of observations, or, in mathematical notation,

$$\mu = \frac{\sum_{i=1}^{i=n} X_i}{n}$$

where

μ is the estimate of the mean of n observations,

(X_1, X_2, \dots, X_n) and $\sum_{i=1}^{i=n} X_i$ is read: "summation

of all values of X_i from its first value to its last value." Mathematical nomenclature can be clarified by a simple example if the monthly demands for a stocked item over a 5-month period are 5, 10, 4, 6, and 5 units, respectively, the

$\sum_{i=1}^{i=n} X_i$ is equivalent to $5+10+4+6+5=30$. The

estimate of the mean (or average) is then:

$$\mu = \frac{\sum_{i=1}^{i=n} X_i}{n} = \frac{30}{5} = 6 \text{ units}$$

The mathematical symbology used in this and subsequent chapters may be somewhat confusing on first examination but should be clarified by the numerical examples which always follow.

b. The reason μ is an estimate of the mean and not the true population mean is that the n observations represent only a small sample from the total population of demands. Since all of the values in a population are rarely known, the science of statistics is usually concerned with estimating parameter values from a small sample of observations.

c. An estimate of the variance can then be found by determining how much each observation varies from the mean, $(X_i - \mu)$. By squaring this value to eliminate negative values, $(X_i - \mu)^2$, adding up these squared deviations,

$$\sum_{i=1}^{i=n} (X_i - \mu)^2,$$

and dividing this quantity by the number of observations minus one (one "degree of freedom" is lost since the mean has already been estimated), the variance is obtained.

$$\sigma^2 = \frac{\sum_{i=1}^{i=n} (X_i - \mu)^2}{n - 1}$$

This expression can then be put into another form for ease of calculation for large numbers

$$\sigma^2 = \frac{\sum X_i^2 - \frac{(\sum X_i)^2}{n}}{n-1}$$

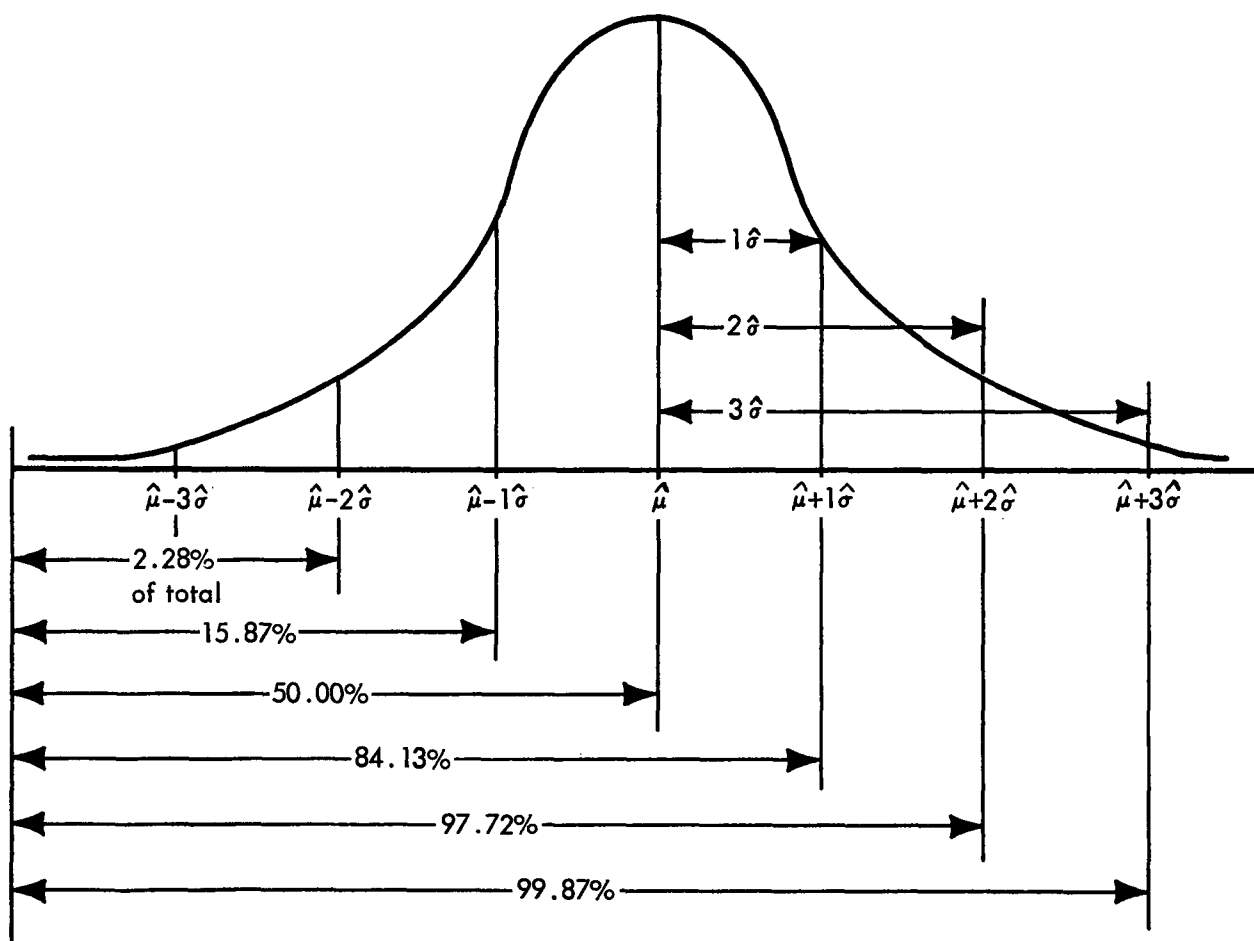
and

$$\sigma = \sqrt{\frac{\sum X_i^2 - \frac{(\sum X_i)^2}{n}}{n-1}}$$

Probabilities, expressed as percentages of the area under the normal (or bellshaped) curve, are shown as a function of μ and σ in figure 34.

133. Illustrative Example

a. A 5-month sample of demands for an item is listed in table 16. The average demand is then six units. It can be seen that the sum of "Quantity Demanded Less the Average" is equal to zero. This will always be the case by the definition of the mean. The reason for squaring this difference now becomes apparent; that is, to eliminate negative values. The reason for finding the square root of the variance to get the standard deviation, then, is to express the deviation from the mean in terms of the original units rather than squared units.



$$SL = k\hat{\sigma} \quad \text{where } k = -3, -2, -1, 0, 1, 2, 3$$

$$Q_T = \hat{\mu} \pm k\hat{\sigma}$$

Figure 34. Probability of the normal distribution as a function of the mean and standard deviation.

Table 16. Five Months' Demands for an Item

Five Months Sample of Demand for an Item

Month	Quantity Demanded (X_i)	Quantity Demanded Less Average ($X_i - \hat{\mu}$)	Square of Quantity Demanded Less Average ($X_i - \hat{\mu}$) ²
1	5	-1	1
2	10	4	16
3	4	-2	4
4	6	0	0
5	5	-1	1
<hr/>			
	$\Sigma X_i = 30$	$\Sigma (X_i - \hat{\mu}) = 0$	$\Sigma (X_i - \hat{\mu})^2 = 22$
	$\hat{\mu} = \frac{\Sigma X_i}{n} = \frac{30}{5} = 6$		
	$\sigma^2 = \frac{22}{4} = 5.5$		
	$\sigma = \sqrt{5.5} = 2.34$		

b. This variance per month can be converted to variance during lead time (if the lead time is fixed) by multiplying it by the number of months of lead time, or

$$VLT = \sigma^2 \times L$$

where

VLT = variance during lead time and
 L = lead time

If the lead time is 2 months, then

$$VLT = 5.5 \times 2 = 11$$

and the standard deviation during lead time ($SDLT$) is the square root of VLT

$$SDLT = \sqrt{VLT} = \sqrt{11} = 3.3$$

Similarly, the average demand during lead time ($ADLT$) for the two-month lead time is

$$ADLT = \mu \times L$$

or

$$ADLT = 6 \times 2 = 12$$

134. Computation of Safety Level

a. The standard deviation is used to estimate the percent of the occurrences which differ from the average by given amounts and based upon the degree of protection desired (percent of time in stock).

b. To illustrate how the standard deviation is used to estimate the probabilities of particular

deviations from the average, the normal distribution is again used. As seen in figure 34, the total quantity demanded (Q_T) is expressed as

$$Q_T = \mu + k \sigma$$

where k can take on any positive value, fractional or integer. It should be noted that Q_T is equal to the reorder point if mobilization reserves are not considered. This expression can be written in terms of lead time demand (Q_{LT}) as

$$Q_{LT} = ADLT \pm k(SDLT)$$

c. For the example shown in paragraph 133, values of Q_{LT} are shown in table 17 with their corresponding probabilities of occurrence. From this table it is seen that 97.72 percent of the time 18.6 or less units will be demanded during lead time. By using this table and knowing the degree of protection desired, the amount of stock that should be on hand or on order when a replenishment order is placed can be determined. For example, if it is desired that the item should be allowed to go out of stock only 1 percent of the

time, the value of k which produces 99 percent protection is 2.326 (from a table of the normal distribution), and the safety level required is

$$SL = k(SDLT)$$

$$SL = 2.326(3.3)$$

$$SL = 7.8 \cong 8$$

The corresponding reorder level is

$$ADLT + SL = 12 + 8 = 20$$

135. Variable Lead Times

If both lead time (LT) and demand during lead time are variable, the determination of SL becomes more complicated. Theoretically, distributions could be fitted to each of these independent variables, but even if this was done the relation to SL to stockouts could not be computed directly. Additional problems arise because LT is really a controllable rather than a random variable, and its distribution has yet to be well defined.

Table 17. Values of Q_{LT} with Corresponding Probabilities of Occurrence

Total Quantity Demanded During Lead Time	Percent of Time This Quantity or Less is Demanded During Lead Time
ADLT - 2 (SDLT) = 5.4	2.28
ADLT - 1 (SDLT) = 8.7	15.87
ADLT = 12.0	50.00
ADLT + 1 (SDLT) = 15.3	84.13
ADLT + 2 (SDLT) = 18.6	97.72
ADLT + 3 (SDLT) = 21.9	99.87

Section III. RELATIONSHIP BETWEEN SAFETY LEVEL AND REORDER CYCLE LEVEL

136. General

A functional relationship exists between Safety Level and Reorder Cycle Level (REOCYL). In general, "the shorter the reorder cycle (or equivalently, the smaller the procurement quantity), the larger the safety level must be to provide equal protection against stockouts." This will become clear in the ensuing discussion.

137. Illustrative Example

a. Suppose a safety level is to be set so that an item will be in stock 95 percent of the time on the average. Two cases will be considered, one with a reorder cycle of 2 years and another with a reorder cycle of 1 year. For both of these cases the procurement lead time (PROLT) is 6 months and the demand rate in the two cases is the same. A graph of these two cases showing the inventory position over a 2-year period appears in figure 35.

In the first case two lead times are encountered, in the second case only one lead time is encountered. To be out-of-stock no more than 5 percent of the time, the out-of-stock time over the whole period is

$$.05 \times 104 \text{ weeks} = 5.2 \text{ weeks}$$

However, in computing safety levels only the lead time periods are of interest. In the first case, the 1-year REOCYL is distributed over two lead times, whereas, in the second case, an out-of-stock condition can occur during only one PROLT. The percent of the lead time that an out-of-stock position can exist for each case is

2-year RCL

$$\frac{5.2 \text{ weeks}}{26 \text{ weeks}} = 20\% \text{ of the lead time}$$

1-year RCL

$$\frac{2.6 \text{ weeks}}{26 \text{ weeks}} = 10\% \text{ of the lead time}$$

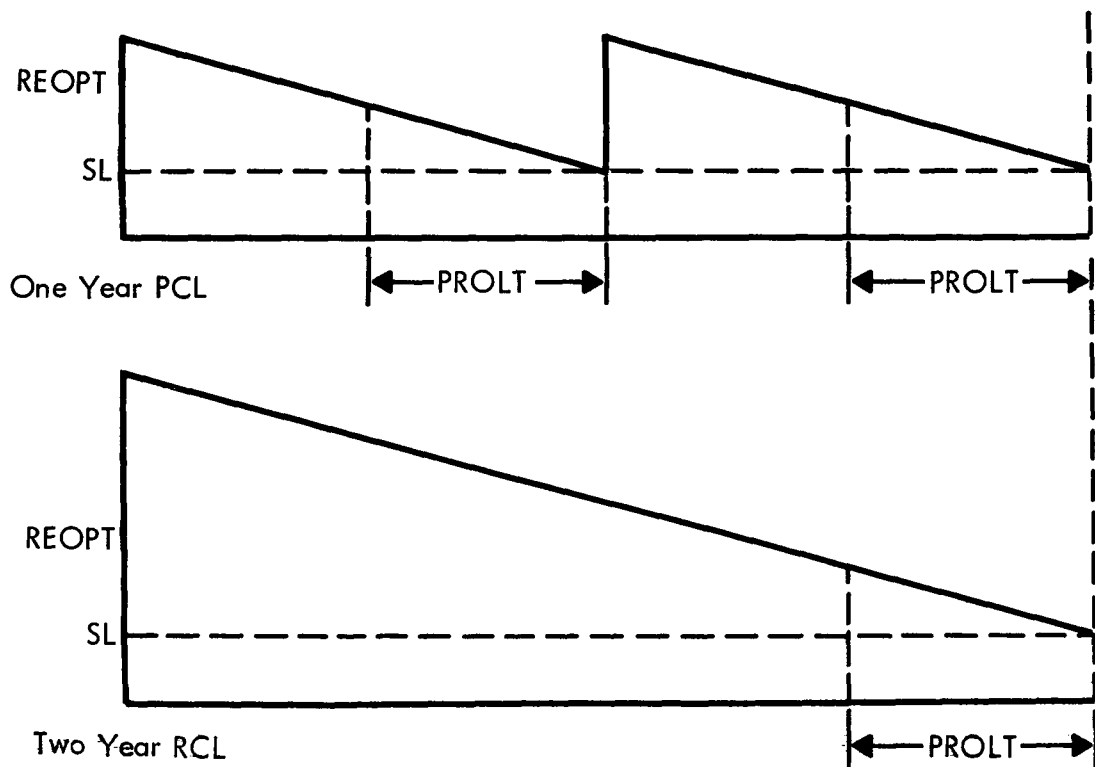


Figure 35. Examples of reorder cycle and lead time.

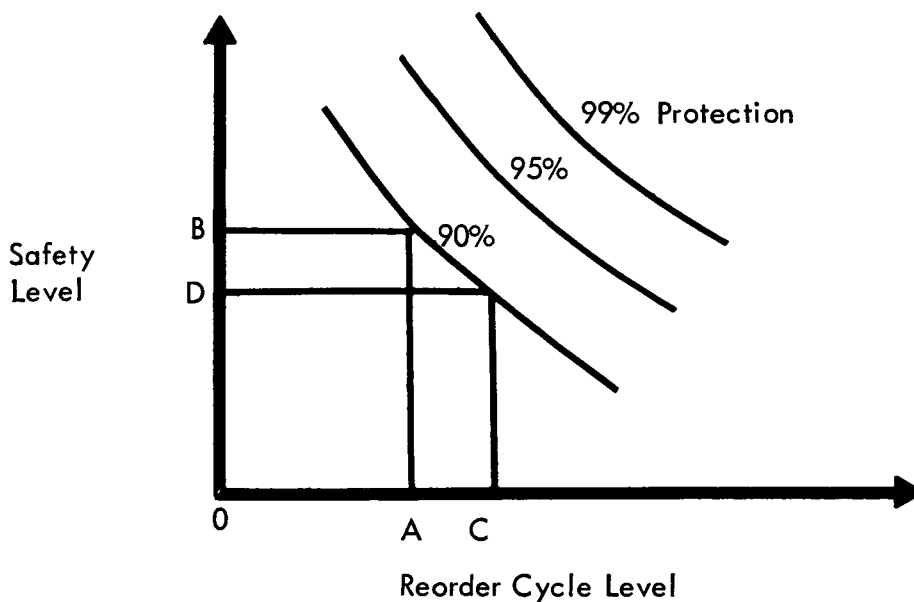


Figure 36. Relationship between reorder cycle level and safety level.

Therefore, an out-of-stock position can occur 20 percent of the lead time and still maintain 95 percent protection in the case of the 2-year REOCYL. In the case of a 1-year REOCYL an out-of-stock position can occur only 10 percent of the lead time and still maintain 95 percent protection. Since a smaller probability of being out-of-stock is permitted in the case of a 1-year REOCYL, a higher safety level must be set in this case to achieve the same overall level of protection. This relationship is illustrated graphically in figure 36. If, for example, the system is operating at a 90 percent level of protection and a reorder cycle of length OA is selected, then the only safety level that will yield 90 percent protection is OB. If a larger reorder cycle

is chosen, say OC, then the corresponding safety level that will yield 90 percent performance is OD, which is seen to be smaller than OB. The net change in reorder cycle level, AC, is not necessarily equal to the net change in safety level, BD, in fact in most cases it will not be. Thus, for a given level of protection a large number of pairs of REOCYL and SL can be found, only one of which minimizes total cost.

b. If a high level of protection (e.g., 99 percent) cannot be achieved within the budget, the VSL concept should *not* be abandoned. Rather, a lower level of protection (e.g., 90 percent) should be used to compute the safety level.

Section IV. VARIANCE-TO-MEAN RATIO

138. Introduction

Many NICP's use as their basic inventory control model a series of procedures that were developed for the Army by a group of mathematicians and scientists associated with the Massachusetts Institute of Technology (M.I.T.). The M.I.T. model makes use of a statistic called the variance-to-mean ration (*VMR*). The *VMR*

provides an easy way of estimating the standard deviation of demand during lead time.

139. Definition

The *VMR* (variance-to-mean ratio) is simply a single parameter which is a measure of both the variance of demand and the mean demand. In general, the greater the average yearly demand (*AYD*), the greater the *VMR*. This means that

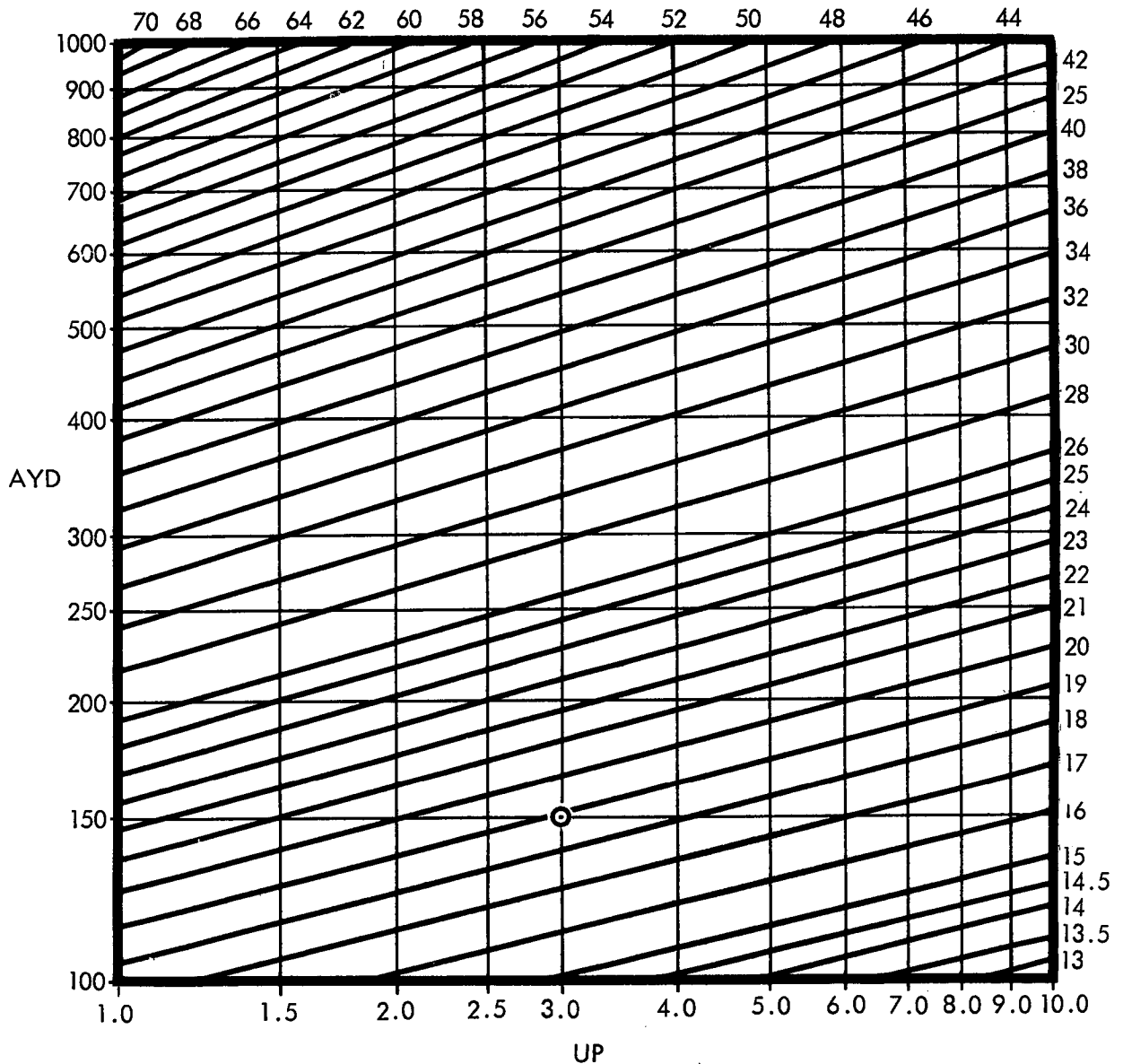


Figure 37. Values of VMR, AYD 100—1000, UP \$1.00—\$10.00.

as the *AYD* increases the variance is increasing at a greater rate than the mean. To determine total annual dollar demand, a unit price (*UP*) must be applied to *AYD*. The *VMR* can be determined from *UP* and *AYD*. Then, assuming holding cost, procurement cost, and *PROLT* are known, a safety level can be computed.

140. Derivation

a. Assuming a compound Poisson distribution of demand (see ch 16) the mean is found to be

$$\mu = \lambda TE(S)$$

where

λ = mean number of demands placed per unit time

T = total planning period

$E(S)$ = the expected value or mean of the order quantities, S .

The variance is found to be

$$\sigma^2 = \lambda TE(S^2)$$

where

$E(S^2)$ = the expected value, or mean of the squares of the order quantities, S^2

Therefore

$$VMR = \frac{\sigma^2}{\mu} = \frac{\lambda TE(S^2)}{\lambda TE(S)} = \frac{E(S^2)}{E(S)}$$

Thus, it is seen that the VMR is independent of the total planning period, T .

b. For manual computation of safety levels, AYD and UP can be arranged on the axes of a nomograph as shown in figure 37. A family of VMR lines can then be drawn to facilitate determination of VMR from known values of AYD and UP . A computer can be easily programed to perform this "hook-up" operation.

141. Procedure for Calculating SL from VMR

a. Once the VMR has been obtained from the nomograph it is convenient to express holding cost (H), ordering cost (C), UP , VMR , AYD , $PROLT$, and the variable lead time (VLT) in terms of three constants, a , b , and Z , which can be tabled.*

b. The value of the Z factor is computed using the formula

$$Z = \frac{C}{H \times UP \times PROLT \times VMR}$$

Knowing Z , values of a and b can then be determined from tables of a , b , and Z .

c. The VLT is calculated using the formula

$$VLT = \sqrt{VMR \times PROLT \times AYD}$$

d. The safety level is determined by using the formula

$$SL = a \times VLT$$

e. The reorder cycle level is computed by using the formula

$$REOCYL = b \times VLT$$

While these are the basic computations involved, the actual computational procedure will have to repeat this procedure a number of times as there are several values of ordering cost and holding cost that apply, and if quantity discounts are present, two or more values of UP must be used.

Section V. MEAN ABSOLUTE DEVIATION (MAD)

142. General

a. There is a good method of approximating the standard deviation which requires less computing time. For the normal distribution, the mean absolute deviation (MAD) is just as accurate as the standard deviation. The relationship between standard deviation and MAD is such that:

$$\text{Standard deviation} = 1.25 \times MAD$$

b. The derivation of MAD is similar to that used for σ .

$$MAD = \frac{\sum_{i=1}^{i=n} |X_i - \mu|}{n}$$

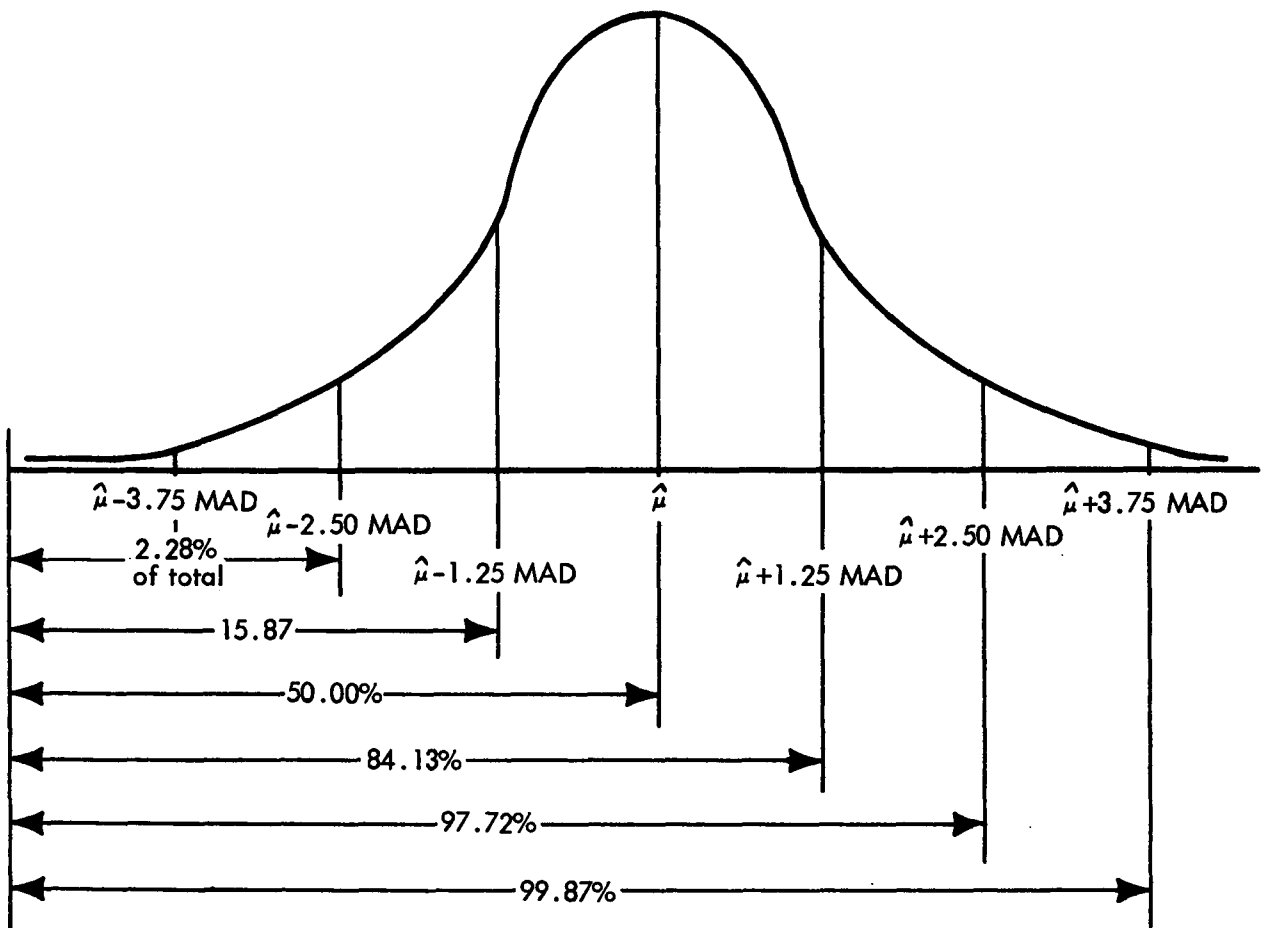
where $|X_i - \mu|$ refers to the absolute value of $X_i - \mu$. "Absolute" means that the deviation is always considered to be positive and that any minus signs are ignored. Calculation of MAD for use in exponential smoothing is as shown in chapter 5.

c. The normal distribution curve shown in figure 34 can be expressed in terms of MAD 's rather than in terms of σ 's (fig. 38). This eliminates the need for constantly multiplying by 1.25.

d. The safety level is then determined for a particular level of protection by first determining k as shown in paragraphs 130 through 135. then

$$SL = k \times MAD$$

*The procedure of setting up tables of a , b , and Z was established in the M.I.T. model.



$$SL = k \text{ MAD} \quad \text{where } k = -3.75, -2.50, -1.25, 0, 1.25, 2.50, 3.75$$

$$Q_T = \hat{\mu} \pm k \text{ MAD}$$

Figure 38. Probabilities of normal distribution as a function of the mean and mean absolute deviation.

CHAPTER 10

SUPPLY CONTROL STUDIES

Section I. GENERAL

143. Scope

a. Section IV, AR 710-45, contains a very comprehensive discussion of how to use DA Form 1794 in completing supply control studies for HDV items. Moreover, all Commodity Command NICP's have issued local SOP's which implement this regulation in the same or greater detail than the original document. For these reasons, detailed instructions for completion of the data entry blocks in DA Form 1794 have been excluded from this manual.

b. Conversely, other than to state the desirability of performing as many routine repetitive computations as possible on ADP equipment, AR 710-45 contains little procedural detail on LDV and MDV item supply control studies. Therefore, in order to best complement the regulation, the two principal sections, II and III, of this chapter expand on the subjects of computerized supply control studies and computer assisted studies.

144. Classifications of Supply Control Studies

a. The three types of supply control studies which will be discussed below are defined as follows:

- (1) *Automated Studies.* Supply control studies performed in their entirety on ADP equipment. Generally all LDV items and many MDV items are included in this category.
- (2) *Computer Assisted Studies.* Supply control studies which make use of ADP equipment for the bulk of the routine or repetitive calculations. The computer output may be a rough facsimile of the DA Form 1794. Many

MDV and most HDV nonrepairable items are included in this category.

- (3) *Manual Studies.* ADPS provides only modest assistance to the supply analyst. The manual completion of the DA Form 1794 and supplementary manual calculations provide the primary basis for the study. Most MDV and HDV repairable items are included in this category. These manual calculations should be reduced by ADP by providing subtotals and summarizations rather than mere listings without totals.

b. The regulation requires that supply control studies be made on the DA Form 1794 for HDV items. Its use is optional in the case of MDV items while it is recommended that it not be used for LDV items. In practice, all NICP's conform to these guidelines with the majority preferring to use the form as a permanent record for most MDV items.

145. Frequency of Supply Control Studies

a. The principles of both selective management and economic inventory control are reflected in the review frequencies currently specified. HDV items, which are often combat essential, where the bulk of the controllable procurement dollars are concentrated and where EOQ's are small in terms of months of usage, are reviewed most frequently. MDV items are reviewed less frequently, and the longest time interval between studies is recommended for LDV items which account for only 10-15 percent of the procurement dollars and which generally have EOQ quantities of greater than a year's usage.

b. The regulation stipulates that complete supply control studies must be made on all

items annually. In addition, studies are to be made whenever the current on-hand and on-order asset level drops below the level of protection provided in the calculated requirements objective, reorder point, or retention point. Supply control studies are also recommended whenever a significant change occurs in demand rate, return rate, or in the variability of demand.

146. Purpose of Supply Control Studies

The main reason for the stipulation of a maximum time interval between supply control studies is to insure a check on the validity

of input data and the resultant demand forecasts as well as for stratification of assets for Financial Inventory Accounting (FIA) and budget purposes. Stock levels can be compared with reorder and warning points quickly and accurately by the computer, but the computer cannot think and apply judgment as can the analyst. Forecasts are projections based on historical demand data or engineering estimates. They are not facts. The computer, however, treats input data as fact. For this reason, there is a recurring need for human intervention and for an analyst to apply subjective reasoning through his audits of supply control studies.

Section II. AUTOMATED STUDIES

147. General

a. A properly programed electronic computer is capable of performing calculations with extreme rapidity and accuracy. ADP equipment can be used to accomplish mathematical tasks which were formerly too complex or time-consuming for clerical staffs. Also, when used in lieu of manpower to achieve savings in information processing time, ADP equipment will normally contribute savings in operating expenses. For this reason, all LDV and many MDV and HDV item supply control studies are being performed on ADPS. These studies may involve a great deal of data and relatively complex mathematical equations, but as long as they can be expressed by a series of simple logical steps (i.e., add or subtract, multiply or divide, less than or equal to), they are suited to computer solution.

b. Conversely, computer cannot make decisions other than those involving simple choices. The logic for an operation must be supplied via a computer program prior to data manipulation. However, the development of a computer program is generally time-consuming and expensive; it must have a repetitive application to be justified. For this reason many HDV item supply control studies are still performed manually. They could be programed for computer solution, but in general it would be uneconomical because many subroutines would have application for only one or small groups of stocked items. Whenever the practi-

cality of automating a manually performed operation is under consideration, the possible effect on stock status lag time should not be overlooked. A reduction in SSLT through improved data processing could result in significant inventory savings which might more than compensate for the high cost of programing.

148. ADPS Operation

In completely automated supply control systems the ADP operation functions as both a watchdog and as a limited decision-maker. Transaction data is fed into the ADPS daily and, on the basis of its stored decision rules (a programed supply management model), the computer determines when a supply action is necessary and often recommends what it should be.

149. Initiation of Automated Studies

a. An ADPS supply control study may be automatically initiated by the computer if any of the following occur:

- (1) Assets on hand, on order and due-in from rebuild fall below the reorder warning point.
- (2) A designated time interval has elapsed the last supply control study.
- (3) The current average demand rate (normally on a quarterly basis) is determined to exceed or fall short of a range based on the previously calculated average demand rate.

- (4) Forecasted average annual demand exceeds the limits established for the items' current inventory classification (i.e., 10% over \$25,000 or 10% less than \$2,500 for a medium dollar item).
- (5) Master file information is determined to be incomplete or inaccurate (through a self-check routine) and requires manual attention.

b. If one of the above criteria is met for an LDV item, the supply control study normally proceeds automatically. However, in some operations (particularly if the item falls into the MDV or HDV classification), a computer printout identifies the problem and the study must then be initiated by a separate input instruction.

150. Automated Study Format

a. The format of the ADPS supply control study derived as computer output differs among NICP's as a function of the specific inventory control model utilized and the amount of manual checking desired. In general, the following data is furnished on a single page of computer printout paper:

- (1) *Identification data.* Stock number inventory classification, unit price, etc.
- (2) *Asset status.* On-hand quantities by location and authorization and status codes, due-ins, due-outs.
- (3) *Requirement stratifications.* PMRMO, PROLT, VSL, etc.
- (4) *Inventory model data.* Reorder warning point, EOQ, special factors such as the "a," "Z," "B" and VMR factors of one inventory control model.
- (5) *Recommended supply action.* In most cases, the procurement quantity.

b. The amount of data printed on the ADPS prepared study should be sufficient to permit the manual review outlined below. The format is immaterial, but should efficiently utilize the hardware and software capabilities of a particular ADPS.

151. Review of ADPS Studies

a. The machine computation furnished the supply analyst are the least cost values of the

requirements elements commensurate with the prescribed level of protection, *provided* the input data used in the calculations were adequate. If any of the data used were inadequate or incorrect, variations from the desired level of protection and least cost operations will occur. This emphasizes the fact that the machine computations must be tempered by the analyst's knowledge of, and experience with the item. Conversely, it is undesirable to recalculate the study manually to correct for minor variations in input data which will result in only negligible changes to the end results. This section, therefore, is designed to provide a practical approach for review of the machine output, outlining the priorities for review and the size of the variations in the data deemed significant enough to warrant a manual adjustment of the study.

b. The priority for review of the machine computations should be based upon the supply control actions indicated. An appropriate sequence is as follows:

- (1) Procurement or rebuild.
- (2) Cutback procurement.
- (3) Disposal.

c. Within the above priority classifications, machine outputs should be reviewed for the following factors: :

- (1) ~~Assets~~ both returns and outstanding ~~procurements~~ should be considered, and duplications and/or omissions corrected. The appropriate inclusion or exclusion of substitute item assets is of vital importance in this classification.
- (2) The remaining life of the end item(s) being supported.
- (3) The mobilization reserves.
- (4) The procurement lead time.
- (5) The authorized retention stock.
- (6) The average yearly demand rate. The importance of the forecasted AYD cannot be overstressed. The analyst should be on guard for demand improperly coded as recurring or non-recurring and for the effect of unusual demands, such as those during the Cuban crisis, which should be excluded from computations.

- (7) The procurement cost.
- (8) The holding cost.
- (9) Comparison to the last two studies, if available.

d. The criteria for adjusting the ADPS supply control study because of a change in one of the above factors should be as follows:

- (1) *Assets*. The asset level should be increased if the item is recoverable and returns are anticipated. The increase in the assets ordinarily will be the reversion rate during the procurement cycle time. Also, the asset status should be reviewed to establish that the input of stock-on-hand, outstanding procurement, due-outs, and the like were reasonable.
- (2) *Life of end item(s)*. The probable remaining life of the end item, in conjunction with the influence that this will have upon the present yearly demand rate for the repair part, should be evaluated. An analysis may reveal that the assets of the item currently on hand and on order will suffice to support the remaining life of the end item. On the other hand, perhaps the computed procurement cycle level should be reduced or extended to provide a lifetime buy which would be more economical in the long term. However, in no case should a buy be initiated which would provide support beyond the time that the item will be phased out of the system. In addition, the probability that the average yearly demand for the item will decrease as the end item is being phased out of the system must always be considered when making a lifetime buy. The analysis of decreased demand should include a consideration of pipeline effects and the contraction that can be expected between echelons (ch 18).
- (3) *Mobilization reserves*. If authorized by NICP policies, mobilization reserve assets may be adjusted by the analyst to meet existing conditions. They may be reduced to meet peacetime requirements and thereby con-

serve funds by reducing the computed buy. They may be increased to compensate for a drawdown, or the drawdown may be permitted to stand and a credit to the conserved funds account accepted. Finally, they may be augmented and thereby cause an increase in the indicated procurement.

- (4) *Procurement lead time*. Changes in the procurement lead time may require change in the computed requirement levels. Depending upon the extent of variation between the "historical" lead time and the standard time being used, it may be desirable to change only the PROLT requirement level or to reflect the change in the variable safety level as well.
- (5) *The economic retention stock*. The life and the use of the end item being supported should always be considered when computing an economic retention stock level. For example, if the remaining life of the end item for U.S. forces is less than the time period represented by the procurable levels, an economic retention stock will not be required. Conversely, it may be appropriate to retain slightly more than normal economic retention stock to preclude possible insignificant procurement quantities near the end of the phase-out period, when the administrative and production cost of procurement would be greater than the cost to hold as inventory. Caution also must be exercised in disposing of excess stock when a density is phasing out for U.S. forces, but a MAP density continues.
- (6) *Average yearly demand*. The AYD should be changed whenever the analysts' best estimate is significantly greater or less than (e.g., ± 10 percent) the machine computed value. In such a case, the entire study must be recomputed.
- (7) *Procurement cost*. The standard procurement cost should be changed and an estimated value used to recompute the requirements levels whenever the

estimated value is more than 400 percent of the standard value or less than 25 percent. (Refer to fig. 28 for effect of overstating or understating ordering costs.)

- (8) *Holding cost.* The standard holding cost will generally remain unchanged. If a change is considered, however, it should be made only when the estimated value is less than 25 percent or more than 400 percent of the standard value (fig. 28). The components of the holding cost which are most likely to lead to a change are deterioration and obsolescence, each of which is normally assigned a value of 5 percent.

e. After consideration of any of the above factors, the machine indicated action may be adjusted for quantity, or a new action may result. When a new action results, the item should be reviewed within the priority of the criteria pertaining to the new action.

f. To further facilitate the review of the machine computed study, the following sequence of evaluation is suggested for the review of the eight factors *c* (1) through (8) above:

- (1) When procurement or rebuild is in-

dicated, the sequence should be as listed.

- (2) When cutback of procurement is indicated, the sequence should be changed so that the AYD is considered second rather than sixth, all other factors remaining in the order listed.
- (3) When disposal is indicated, the sequence should be—
 - (a) Consideration of AYD.
 - (b) The remaining life.
 - (c) The other factors in their respective order.

152. Summary

In summary the purpose of the preceding discussion has been to show that the ADPS computation presents only a systematized, routine approach to the supply control study. The repetitive and routine calculations are removed from the analyst and placed upon the machine. Most of the decision and judgment considerations, however, remain with the analyst, and only when adjustments will have little influence upon the end result have they been restricted. The supply analyst, therefore, must continue to maintain prudent control of his items. He cannot relinquish this responsibility to any mechanical procedure.

Section III. ADPS ASSISTED STUDIES

153. General

a. ADP equipment at most NICP's is programmed to signal the requirement for an HDV or MDV item supply control study on the basis of daily transaction data in much the same fashion as for LDV items.

b. In addition, as these higher annual demand classifications normally have a smaller operating level and a larger proportion of their assets in a due-in status, computer programs normally incorporate another signal point—the level at which assets due-in must be expedited to preserve on-hand quantities at a level to assure supply effectiveness.

c. In conjunction with a study requirement signal, the computer may automatically perform various calculations and printout the re-

sults in a form which closely approximates a DA Form 1794. More often, the computations are performed as a separate step in the sequence indicated below:

- (1) Requirement for supply control study determined in ADPS.
- (2) Supply management personnel provide selected input data for the study on a standardized locally prepared form.
- (3) ADPS performs a major portion of the supply control study.
- (4) Supply management personnel review ADPS study for HDV items, transcribe much of the included data to a DA Form 1794, and complete the study manually on the DA Form.

154. ADPS Computations

a. ADP equipment is best utilized for operations which recur with sufficient frequency to justify the initial programming effort. These operations often involve great quantities of data and may or may not incorporate complex mathematical equations. The best illustrations of supply control study operations which lend themselves to computer solution are—

- (1) Calculation of variable safety levels.
- (2) Calculation of economic order quantities.
- (3) Smoothing of demand rates.

b. The bulk of the input data required for ADPS calculation of VSL's and EOQ's exists in the master tape file. Studies can be performed on request without further input unless there is a need to reflect the peculiar characteristics of an individual stocked item. Examples of specific information could include an unusual ordering or holding cost, a special level of protection, or data on quantity discounts.

c. ADP equipment can be very effectively used to smooth demand data for use in the forecasting of requirements. Several smoothing techniques are discussed in chapter 5. Some of those techniques, such as exponential smoothing, are more efficiently incorporated in computer routines, but all are capable of being programmed for ADPS solution. As an example of the steps a computer would follow in performing a simple (but laborious if performed manually) calculation procedure, consider the following test of demand data for a pattern of seasonality.

- (1) The master record contains 2 years of demand data totaled by month.
- (2) The corresponding demand for the same month in each year is added (i.e., demand for May 1964 added to demand for May 1965).

(3) The resultant 12 quantities are divided into four quarterly groups:

- (a) Group 1 = January, February, March
- (b) Group 2 = April, May, June
- (c) Group 3 = July, August, September
- (d) Group 4 = October, November, December

(4) The four group totals are then obtained, and an average for the four groups is also obtained.

(5) The greatest group total is then compared with the average. If it exceeds the average by more than 30 percent, a seasonal peak is assumed to exist.

(6) If a seasonal characteristic is not detected, a rearrangement of the four groups in step (2) above, is made, beginning Group 1 with February and ending Group 4 with January (i.e., Group 1 = February, March, April).

(7) Steps (4) and (5) above are repeated.

(8) If a seasonal characteristic is not detected, the final combination of three-month groupings is explored, beginning Group 1 with March.

(9) If a seasonal peak is not detected in any of the three cases, the item is considered to be nonseasonal. This entire check for seasonality would take less than a second in a typical NICP computer installation once the data is available in core storage.

d. NICP's should continually strive to incorporate more of their repetitive data manipulation operations on ADPS. In addition to their time and cost advantages, ADP equipment can contribute immeasurably to improved accuracy. It is not unusual, for example, for modern automatic data processing systems to perform as many as 100 million operations per error.

Section IV. DA FORM 1794 CONSIDERATIONS

155. General

a. DA Form 1794 was specifically designed for use in completing HDV item supply control studies using the major oversea depot method. However, as has been noted earlier, it is often

used for selected items in other categories. In these cases, sections I and II of the form, for USARPAC and USAREUR data, are left blank.

b. When used properly and with accuracy,

the DA Form 1794 will insure the achievement of performance goals at minimum cost. Use of the form will not, however, serve as a panacea for all supply management problems. It has certain limitations which should be clearly recognized.

156. Limitations

a. DA Form 1794 is used on manually performed supply control studies and therefore inherently contains all the shortcomings common to manual operations. Many opportunities for human errors in accuracy and judgment exist in the sections, columns, and rows of the form. The importance of exercising diligence and care in the completion of the study form cannot be overemphasized. Analyses of small samples of completed study forms from several NICP's have indicated that about one in three will contain at least one arithmetical error.

b. The format of the study form is organized for clarity and simplicity, but does not provide any method of emphasizing sections or lines of particular significance. The most important element in determining the amount of the procurement or rebuild quantity is normally the forecasted average quarterly demand rate. Since the AQD is based upon the historical demand and the program change factor, each of these figures must be as accurate as possible. The relevancy and accuracy of the demand figure must be carefully substantiated. Of utmost importance in this regard is the proper separation of demand into the recurring and nonrecurring classifications. The program change factor, in turn, should be computed by using an appropriately sensitive demand smoothing technique and, if possible, be double-checked by obtaining forecasts of anticipated usage from the principal consumer organization.

c. Section IX, Remarks, was afforded little space on DA Form 1794 in order to minimize the overall size of the sheet. It is important that this section receive the attention it is due. The analyst should flag in the Remarks Section all entries which, because of their importance or unusualness should be called to the attention of reviewers. Similarly, the absence of any key data should be noted. The

existence of backup data for nonroutine calculations should be clearly stated, and if possible, this data should be attached to and forwarded with the study form. In addition, AR 710-45 lists specific factors of the supply control study which should be explained in the Remarks Section.

- (1) Planning for repair backlog in future time frames.
- (2) Basis for selection of a particular course of supply action.
- (3) Impact and cause of stock imbalances.
- (4) Comparison of actual demand patterns with those forecasted in earlier studies completed during the past 12 months.
- (5) Use, if any of data on worldwide assets to support proposed supply control actions.

157. Cautions

a. To insure arithmetical accuracy, the computations on DA Form 1794, as well as those which support such components as program change factors, should be double-checked by a second analyst not responsible for the initial preparation of the study form.

b. As discussed in chapter 3, a formal review procedure should be established which provides that the number of reviews and depth of detail in each review is proportional to the importance of the supply action to be taken.

c. Associated entries on the study form should be checked for accuracy, and any inconsistency should be noted and explained in the Remarks Section. For example, the administrative lead time figure in block 20 should be of the same order of magnitude as recent actual lead time shown in Section VI, lines 44 to 47.

d. The thoroughness of coverage provided by the Remarks Section should be insured through the use of a checklist or, as has been done by some NICP's by an overprinted form for supplementary data on the back of the standard DA Form 1794.

Section V. SUPPLY CONTROL STUDIES IN OVERSEA THEATERS

158. Calculation of Requirements

A discussion of the calculation of requirements in oversea theaters was presented in paragraphs 75 through 77.

159. Supply Control Studies

a. Oversea items which are ordered on an EOQ basis (equivalent to LDV items) are generally studied with ADP or EAM equipment. Items which fall into the higher annual dollar demand classifications are studied manually.

b. Several manual supply control study forms are in use in oversea theaters. A typical example contains the following major blocks for data entry and computations:

- (1) Management data.
- (2) Substitute data.
- (3) Demand data.
- (4) Density data.
- (5) Requirements.
- (6) Stock status data.
- (7) Computations.
- (8) Remarks and judgment.

c. These manual forms somewhat resemble DA Form 1794 but are not time-ordered in the manner of the DA Form.

d. Studies are presently in progress in oversea theaters which are expected to result in greater centralization of supply management. Should this objective be realized, it will be both desirable and possible to achieve greater standardization of procedures and forms.

CHAPTER 11

REPAIRABLES

Section I. GENERAL

160. Introduction

a. The discussion of supply control procedures thus far has placed primary emphasis on the situation where replenishment stocks are provided through procurement actions. Many of the secondary items in the Army supply system are economically repairable, however, and appropriate consideration of these items enormously complicates the decision-making problem. In the case of repairable items, many more variables must be considered, and their interrelationships are very difficult to visualize on an intuitive basis.

b. As mentioned above, replenishment of items in the supply system can be accomplished in two ways from—

- (1) New procurement.
- (2) Repair or overhaul of unserviceable but repairable items.

In the new item procurement system, the only uncertain functions are the variabilities of demand and lead time. In a repairables system, however, variability in the return rate of unserviceable items must also be considered. Setup costs as well as accumulation and lead times for the repair action must be included in analyses in addition to the now familiar setup costs and lead times for procurement. Also, the question of quality of service expected from a repaired item versus the service expected from a new item must also be faced. For these reasons, the problems involved in formulating a mathematically optimal solution to the repairables decision problem are considerably more complex than for their nonrepairable counterparts in the supply system.

c. This chapter does not attempt to “solve” the repairables problem; its purpose is to give

insight into the various problems posed by a repairables system.

161. The General Repairables Problem

a. The general problem of the repairables system is the determination of when repair and procurement actions should be initiated so as to maintain a stated level of availability of serviceable items. In addition, the quantity of items to be repaired or procured in each such action must be determined so that the total cost function is minimized. In other words, the two basic inventory questions of “how much” and “when” now require four answers because each contains the dual elements of procure and repair.

b. In this discussion of repairables, principal emphasis will be placed on replenishment actions at the NICP level (i.e., depot repair and wholesale procurement). The costs being considered are the cost of repair actions, the cost of initiating repair and procurement actions, and the costs of holding serviceable and unserviceable inventory.

162. Supply Control Studies

a. A brief description of current procedures for dealing with repairables is presented below as background for a more detailed discussion of the repairables problem in later paragraphs.

b. DA Form 1794 provides for the accumulation of data regarding average quarterly returns (AQR) of repairable items in addition to total average quarterly demands (AQD). Both of these quantities are normally calculated as moving averages, usually over a base period of eight quarters. A repairable return ratio for the current period is computed by

dividing AQR by AQD. Repairable returns are then forecasted for future periods by multiplying forecasted recurring demands by the repairable return ratio.

c. The repairable returns for the current period represent—

- (1) Scheduled and unscheduled repairable assets on hand in depots as shown by the stock status report.
- (2) The repairable stock expected to return to the system in the interval between the stock status cutoff date and the date of the study.

d. If the overseas theaters have the capability and authority to repair particular items, the theater which generates a repairable-unserviceable item enters the forecasted repair quantities as part of the total theater assets. If the theater does not have the capability or authority to repair these items, then the forecasted quantities are entered parenthetically and are not included in total theater assets. Instead, since the items are sent to CONUS depots for repair, the repair quantities are added to the repairables forecast for CONUS depots.

163. Current Review Policy for Repairable Items

a. The current review policy for repairable items proceeds in approximately the following sequence:

- (1) Set a reorder point based on lead time for new procurement only.
- (2) When on hand and due-in assets reach this recorder point, order a replenishment quantity.
- (3) Satisfy the replenishment requirement first by repair of unserviceable stocks that are economically repairable to the extent they are available. An unserviceable item is defined as economically repairable if it can be restored to serviceable condition at a cost equal to or less than some specified fraction of the cost of a new item.
- (4) Fill the balance of the replenishment requirement, if any, from new procurement.

b. One problem this policy fails to treat adequately is the possibility that the repair cycle time will be different from the procurement lead time. It is apparent that in this case a single reorder point is not adequate. The fact that a mixed replenishment quantity exists, made up of both new and repaired materiel, must be considered. In addition, setup costs involved in procurement and repair must be considered for a truly optimal policy decision to be made. In brief, EOQ's for procurement and repair will differ and are both interrelated and dynamic.

164. Input Parameters of the Repairables System

a. It is useful to identify the input parameters that must be considered in a repairables system. These include—

- (1) Average demand rate.
- (2) Variability of demand.
- (3) Average return rate.
- (4) Variability of returns.
- (5) Procurement setup cost (administrative and manufacturing).
- (6) Repair setup cost (administrative and repair).
- (7) Procurement lead time.
- (8) Repair cycle time.
- (9) Unit price of a new item (direct cost only).
- (10) Unit cost of a repair action (direct cost only).
- (11) Holding cost for serviceable items.
- (12) Holding cost for unserviceable items.
- (13) Level of availability.

b. Variability in demand rates and return rates is discussed further in paragraphs 165 and 166. Cost considerations for new parts were discussed in detail in chapter 7. Repair setup cost, unit cost of a repair action, and holding cost for a repairable item are similar in nature to the procurement cost, unit price, and holding cost of a new item, respectively. The problem that arises, in the repairable situation, however, is that of determining each of these costs with an acceptable degree of accuracy. Another problem requiring attention is the problem of continuous repair versus repair by economic lot. The concept of repair by economic lot is similar to the determination

of EOQ in that all of the pertinent costs must be balanced to determine what lot size to accumulate before initiating a repair action.

c. The relative worth of new items as opposed to repaired items presents an additional parameter, and one that is difficult to quantify.

Section II. SOURCES OF DATA VARIABILITY

165. Demand Variability

a. Demand variability, as discussed in earlier chapters, results from at least the following factors:

- (1) Item failure or wear out.
- (2) Item phase-out or obsolescence.
- (3) Introduction of new items into the system.
- (4) Emergency (short-term) buildup.
- (5) Gradual (long-term) buildup.
- (6) Troop movements.
- (7) Expansion and contraction of the pipeline.
- (8) Seasonal or cyclical variability.
- (9) Random fluctuations.

b. All these sources of variability must be considered if an optimal inventory policy is to be attained. In fact, it is the mission of modern inventory management to respond to these changes in the course of maintaining a predetermined level of desired performance.

166. Return Rate of Unserviceable Items

a. As the Army inventory system responds to variations in demand with both newly procured items and repaired items, a new element of variability arises; this is the variability in rate of return of unserviceable items. The return of unserviceable items is a key element in the repairables cycle, which normally proceeds as follows:

- (1) Return of unserviceable items for repair.
- (2) Repair or overhaul of these items.
- (3) Return of these repaired items back into the system (for use of inventory).

b. The last two parts of this cycle are subject to managerial control. The first part, however, is a variable element and one that

It cannot normally be determined, with any degree of certainty, how long a repaired item will last under field usage conditions. The problem is not only one of minimizing the total outlay of money; rather, it is one of determining a policy that produces the greatest number of days of field usage per dollar spent.

is difficult to forecast. In this regard, a system of forecasting removals (returns of unserviceable items) has recently been developed by the Air Force and is being used by the Army for aviation parts under the Aviation Maintenance Management Improvement Program (AMMIP) (ch 13). This system, known as an actuarial forecasting system, is based upon the assumption that accurate usage records are kept in terms of "hours of operation." Unfortunately, although this assumption is usually valid for aircraft components, it is not normally true of other types of Army materiel, which are not inspected and repaired according to a prearranged schedule. Since most Army equipment is maintained under the IROAN (Inspect and Repair Only As Necessary) policy, the rate of return of repair parts for this equipment has an element of randomness not usually found with aircraft components.

c. The actuarial system of forecasting removals was discussed in chapter 5 with other forecasting techniques. A brief summary of this system will be repeated here, since it bears directly on the repairables problem. This procedure is actuarial in the sense that it forecasts the expected length of time a part will survive before failure or removal. To do this, a survival probability curve is plotted that describes, for each flying hour, the fraction of all items which survive this age without removal. Next, the expected number of removals in the forecast period is computed for a given flying hour program. In addition to the previously computed survival probabilities, this step requires the ages of the currently installed items as well as the average age of the items in the supply system with which these installed items will be replaced if they are removed.

d. In the system described above, the rate of return of unserviceable items can be forecasted reasonably well because parts are removed for repair and overhaul on a basis of the time used rather than when they break

down. In general, however, rates of return cannot be so closely correlated with item usage and failure, making accurate forecasts more difficult.

Section III. OTHER CONSIDERATIONS

167. A Generalized Repairables Model

a. Aside from the rather specific AMMIP model that depends upon the availability of usage data, attempts to develop a generalized model for repairable items have so far been unsatisfactory. Repairables are a problem because of the number of variables that must be considered. To describe adequately a repairables model, a series of decision rules must be stated and addressed in a sequential order. For example, one approach to an optimizing repairables model has been stated as follows:

- (1) Set two reorder points, one for initiating procurement and the other for initiating repair.
- (2) Consider a cycle to be composed of a procurement action followed by some number of repair actions with a new cycle beginning with the next procurement action.
- (3) Start a cycle by ordering some quantity Q_p from procurement. When the on hand and on order assets reach the procurement reorder point R_p , determine whether the unserviceable assets expected to be on hand when the repair reorder point R_r is reached are equal or greater than some repair quantity Q_r . If they are, wait until R_r is reached and initiate a repair order for quantity Q_r . Continue to initiate repair orders in this manner until the unserviceable assets expected to be on hand when R_r is reached are less than Q_r . When this is the case, order a Q_p from procurement (observe that this action is initiated when on hand and on order assets reach R_p). This policy is graphically illustrated in figure 39.

b. It has not yet been determined whether or not such an approach is practicable. This de-

termination must be made through the use of simulation techniques, or a controlled field test, before any extensive implementation of the proposed system can be initiated. Assuming this approach is proved practicable, it should be possible to construct a model for determining the values of R_p , R_r , Q_p , and Q_r for individual items. The problem then is to set these values so that a given level of availability of serviceable items is maintained while minimizing a cost function that includes all pertinent costs.

c. The next question has to do with how the availability of serviceable stock is to be controlled and measured. In the situation where only new procurement is considered, the question is straightforward in that a complete cycle consists of only the period between successive procurement actions. In this case, the only period in which stockouts can occur is the procurement lead time. For this reason, the safety level portion of the reorder point quantity is based on consideration of only the demand variability during the procurement lead time. However, in the situation where repairables are also used for replenishment, the availability of serviceable stock over a complete cycle can be insured in several different ways. If, for example, it is desired to maintain 95 percent availability, out-of-stock conditions can occur in any one of the following ways:

- (1) During the procurement lead time only.
- (2) Concentrated during one or more of the repair lead times.
- (3) Equally distributed over all the repair lead times.
- (4) Equally distributed over both the procurement and repair lead times during a complete cycle.

The proponents of this approach have tentatively recommended the adoption of the fourth alternative—equal distribution of probability

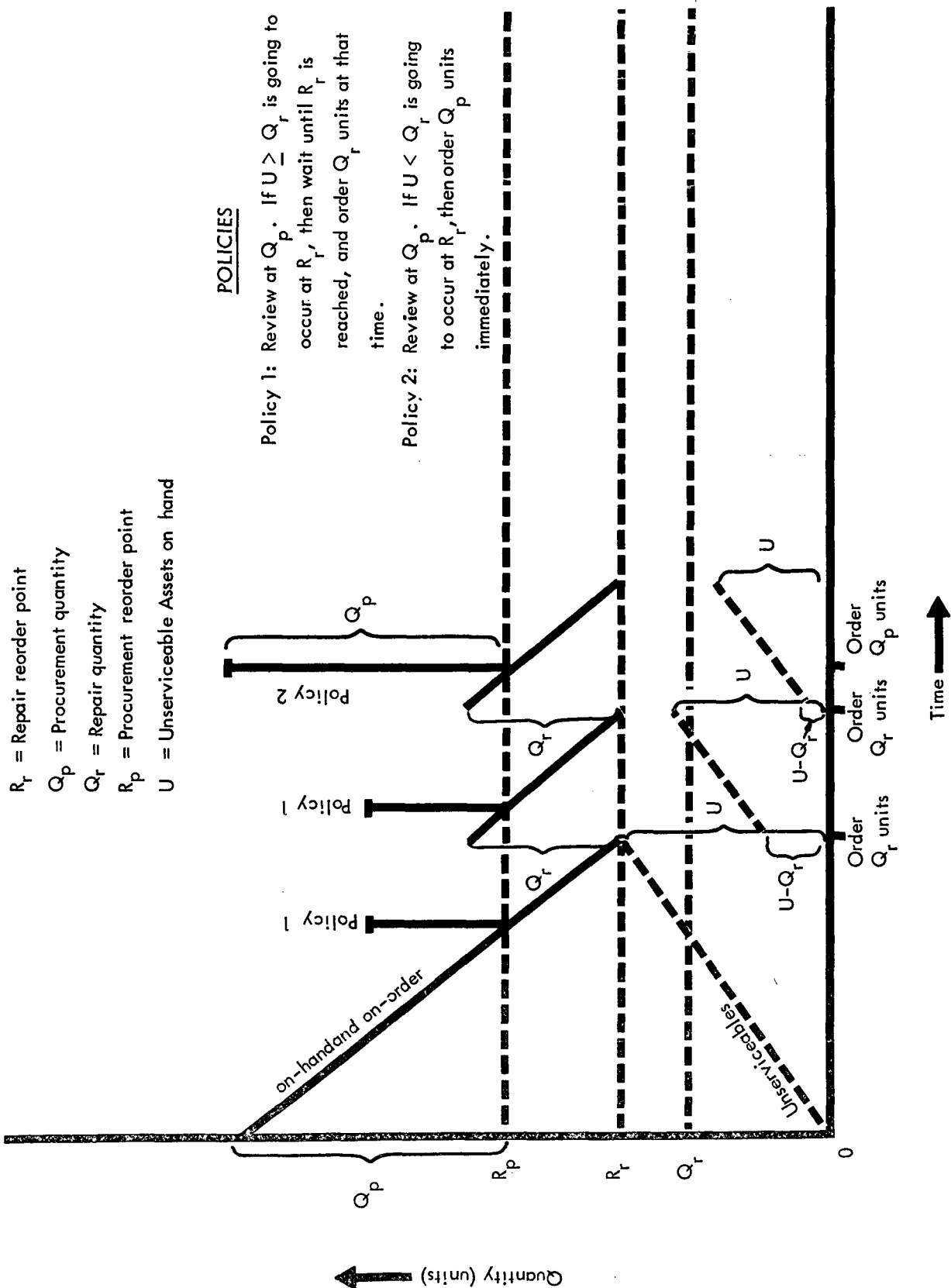


Figure 39. First repairables model.

of stockouts over both procurement and repair lead times.

168. Cost Considerations

a. Repairable items pose a unique problem when their costs are subjected to analysis. The several types of funds (PEMA, ASF, OMA, etc.) utilized in the logistics system have been discussed in earlier chapters. It was mentioned that they differ in use (investment costs versus operating expenses) and in availability. Further, it has been pointed out that policies are available that minimize the need for one type of money at the expense of another. A thorough consideration of funding interrelationships is even more critical when repairable materiel is involved. This point can be illustrated by the following example:

- (1) Assume an item has the following input parameter values:
 - (a) Demand rate = 1 unit/day
 - (b) Return rate = 0.8 unit/day
 - (c) Procurement setup cost = \$120

- (d) Overhaul setup cost = \$50
- (e) Direct manufacturing cost = \$1.00/unit
- (f) Direct overhaul cost = \$.30/unit

(2) Consider the following cases:

- (a) Case I: An initial procurement of 180 units (6 months of supply)
- (b) Case II: An initial procurement of 360 units (12 months of supply)

(3) Additional simplifying assumptions:

- (a) Procurement and overhaul are assumed to be instantaneous.
- (b) Holding costs are not considered.
- (c) Demand and return rates are assumed to be known and constant.

b. Sawtooths diagrams for each of these two cases appear in figure 40. Each case is begun with newly procured stock which is used until exhausted. By that time unserviceable stock has been accumulated and repaired. This repaired stock then becomes usable stock, which is used until it, in turn, is exhausted. In the

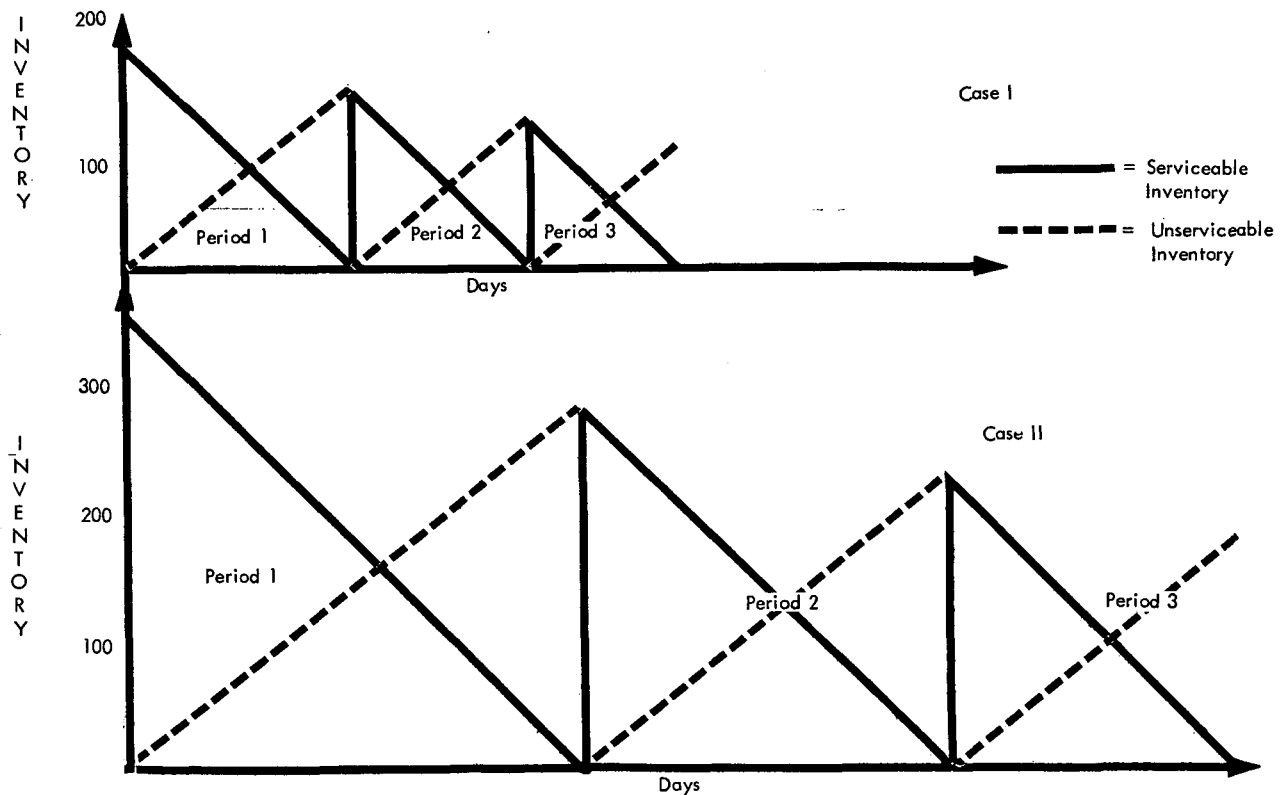


Figure 40. Effects of procurement quantity on operating cost and inventory.

meantime, additional units are being accumulated and repaired, and so the cycle proceeds.

The total costs resulting in each case are then as follows:

Case I:

Period 1 (Procurement of 180)

$$\begin{aligned} \text{Total Manufacturing Cost} &= \$120 \\ &+ \$180 = \$300.00 \end{aligned}$$

Period 2 (Repair of $180 \times 0.8 = 144$)

$$\begin{aligned} \text{Total Repair Cost} &= \$50 + (144 \\ &\times \$0.30) = \$93.20 \end{aligned}$$

Period 3 (Repair of $144 \times 0.8 = 115$)

$$\begin{aligned} \text{Total Repair Cost} &= \$50 + (115 \\ &\times \$0.30) = \$84.50 \end{aligned}$$

Total manufacturing and repair cost for three periods = \$477.70

$$\begin{aligned} \text{Cost per day} &= \frac{\$477.70}{439 \text{ days}} \\ &= \$1.09 \text{ per day.} \end{aligned}$$

Case II:

Period 1 (Procurement of 360)

$$\begin{aligned} \text{Total Manufacturing Cost} &= \$120 \\ &+ \$360 = \$480.00 \end{aligned}$$

Period 2 (Repair of $360 \times 0.8 = 288$)

$$\begin{aligned} \text{Total Repair Cost} &= \$50 + (288 \\ &\times \$0.30) = \$136.40 \end{aligned}$$

Period 3 (Repair of $288 \times 0.8 = 230$)

$$\begin{aligned} \text{Total Repair Cost} &= \$50 + (230 \\ &\times \$0.30) = \$119.00 \end{aligned}$$

Total manufacturing and repair cost for three periods = \$735.40

$$\begin{aligned} \text{Cost per day} &= \frac{\$735.40}{878 \text{ days}} \\ &= \$0.84 \text{ per day.} \end{aligned}$$

c. It can be seen from this example that doubling the initial inventory investment has decreased operating costs by 25 percent. It should be emphasized that this simple comparison only attempts to compare direct manufacturing and repair costs with setup costs for the two different replenishment quantities. It does *not* consider the total cost function which also includes, as a minimum, holding cost.

d. One question that remains to be answered in this example is whether an investment dollar (e.g., Army Stock Fund) is equivalent to an operating dollar (OMA) in the practical world. If, in fact, this is true, then it is possible to formulate a repairable model so as to minimize total variable costs over a complete cycle of procurement and repair actions.

169. Conclusion

a. Much work remains to be done in the development of an optimal model for repairable items. However, research efforts are being expended on this problem in the Armed Services as well as in private industry. It is likely that new insights will be gained in the near future through the application of simulation and operations research techniques on new, powerful computers.

b. In the meantime, commodity managers and supply analysts should fully recognize that repairables do constitute a special problem, one that requires more attention and a greater application of disciplined judgment. It is in this control area, the one which cannot presently be computerized, where they should concentrate their analytical efforts.

CHAPTER 12

STANDARDS AND PERFORMANCE EVALUATION

Section I. GENERAL

170. Introduction

a. Well-designed management control systems provide for the functions of measurement, evaluation, and correction. Expressed another way, it is imperative that a management system incorporate a feedback loop that permits adjustment of out-of-control situations.

- (1) Measurement is primarily a data collection and data processing function. A good measurement system provides accurate and timely data organized in a fashion that will facilitate its evaluation.
- (2) Evaluation involves the analysis of current or projected status in the light of defined standards and objectives. Several courses of action are generally evaluated in terms of their effect on the system (performance) and their use of resources (cost). One of these courses of action must ultimately be selected by the decision-maker.
- (3) Correction involves doing something within the system to implement the selected course of action. The corrective action thus completes the feedback loop that began with a measurement of the system's current status.

b. This chapter is primarily concerned with the establishment of supply management operating standards and their use in performance evaluation.

171. Needs for Standards

a. A standard, in the context of this chapter, is defined as a quantitative target. It may be a goal, in the sense that it should be strived for but not necessarily achieved, or a base

point, a level below which performance will not be tolerated.

b. Standards are established for many reasons but primarily to provide managers with yardsticks which they can gauge their performance and progress. To function effectively, a supervisor must know what is expected of him. Similarly, the operation of a logistics system must be periodically evaluated in terms of predetermined standards. However, these standards need not be rigid. As improvements are made in the operation of a system, new performance standards should be set to reflect the changes. Conversely, if the system is constrained (as by a funding limitation), lower standards should be established—if only on a temporary basis.

c. In supply management activities, current standards fall into one of two categories.

- (1) Service performance.
- (2) Cost performance.

Service performance is concerned with how well the legitimate demands of consumers are met by the supply system. Cost performance, on the other hand, relates to the cost of obtaining a given level of service. It will be shown in later sections that cost and performance are closely interrelated.

172. Precautions in the Use of Standards

a. Properly selected standards have been described as a necessary part of a management control system. Great care must be exercised in their selection, however, as poor standards can be worse than none at all. Once established, a standard influences decision-makers. An improper standard can result in incorrect decisions. A standard that sets an unobtainable goal may be self-defeating because it frustrates

managers and creates an atmosphere of pessimism. On the other hand, too low a standard implies acceptance of poor performance, and managers may lack sufficient motivation to perform at their full capability.

b. Standards should be selected that are capable of being clearly defined; no confusion should exist as to the meaning of the standard. Similarly, the measure of actual performance that will be compared with the standard should be easily obtained. The calculation should be straightforward and the choice of input data precisely defined. This is necessary to prevent reporting errors as well as data manipulation.

c. Finally, standards should be meaningful. They should be a true and accurate measure of an important and controllable activity. Most successful managers concentrate their attention on a few indexes that reflect the condition of the most critical aspects of their operation. The principle of selective management is fully applicable in the choice of the quantity and type of performance standards. In this regard, a standard should be systems-oriented to the maximum extent practicable; that is, it should strive to measure the degree of fulfillment of the overall logistics mission instead of only isolated cost or performance elements.

Section II. MEASURES OF PERFORMANCE

173. Service Performance

a. The most common measures of performance used in supply management are those which attempt to evaluate performance in terms of service to customers. Many standards fall into this classification, among them are the following:

- (1) Percent out-of-stock.
- (2) Percent items on time.
- (3) Percent initial fill.
- (4) Percent of requisitions satisfied.
- (5) Average wait.
- (6) Item years of wait per year.
- (7) Average back orders.
- (8) End item downtime.
- (9) Percent availability.

The definitions, uses, and limitations of these indexes are discussed in *b* through *k* below.

b. A measure of performance used at all NICP's and generally afforded a high level of management emphasis is the percent out-of-stock, most frequently defined as—

$$\% \text{ Out-of-Stock} = \frac{\text{Number of line items out-of-stock}}{\text{Total number of line items}}$$

This index should include only stocked items in the numerator and denominator to be meaningful (i.e., demands for items not included

on authorized stockage lists should be excluded from the calculation). This index has the advantage of being easily defined and may be readily computed on ADPS from data carried in the master tape file. It tends, however, to oversimplify the actual condition of the inventory for four reasons:

- (1) It primarily measures variability of demand over lead time and is not related to order quantity.
- (2) It measures performance at only the wholesale (national) level, and this may not be representative of the service obtained by the consumer in the field.
- (3) It provides an overstatement of the losses incurred, since it costs nothing to be out-of-stock when no demands for an item are being received.
- (4) It presumes that items have been correctly categorized as stocked or non-stocked and that the basis for this classification (AR 711-25) is optimal in the context of the total logistics mission.

c. Another performance measure that has been looked at rather closely at NICP's is the on time shipment to ports measure. This is defined as—

$$\% \text{ of Items on Time} = \frac{\text{Number of line items shipped to ports by required date}}{\text{Total number of line items shipped to ports}} \times 100$$

This index measures how well an NICP is meeting a rather limited objective but may have little meaning so far as the operation of

the total inventory system is concerned.

d. A third measure used frequently is the depot initial fill percentage, defined as—

$$\% \text{ Initial Fill} = \frac{\text{Number of requisitions satisfied by the required date by the initial source depot}}{\text{Total number of requisitions received by the initial source depot}} \times 100$$

Several points should be made about this measure. First, it is closely watched by distribution depots but is not accorded the same degree of interest at the NICP level. Second, the use of this measure implies that a high percentage of initial fill would indicate a healthy supply system. In practice, however, most NICP's do not transship (redistribute) stocks among distribution depots. This is because numerous studies have indicated that the costs associated with a depot stock bal-

ancing program are greater than the costs of making occasional expedited shipments from a more distant point. Further, the real pay-off in the operation of a supply system comes on performance measured at the consumer level—a performance shown to have little correlation with initial fills at distribution depots.

e. One of the inventory models now used by many Army NICP's makes use of a performance measure defined as follows:

$$\% \text{ of Requisitions Satisfied} = \frac{\text{Number of requisitions satisfied on time}}{\text{Total number of requisitions received}} \times 100.$$

In this definition, a requisition is considered satisfied if it can be filled by any of several distribution depots by the customer's required date. One weakness of this measure is that it does not differentiate between the number of requisitions and the number of units demanded on each requisition. An unfilled requisition for

one unit is afforded equal weight with one for 500 units. The relevancy of this index as a measure of performance is discussed in greater detail in chapter 13.

f. The length of the time interval spent waiting for delivery of a requisitioned item is measured by two slightly different indexes—

$$(1) \text{ Average wait} = \frac{\text{Total time waited until stock is received on requisition not filled by initial source depot}}{\text{Total number of items not filled by the initial source depot}}$$

$$(2) \text{ Item Years of Wait per Year} = \frac{(\text{Number of items not supplied by initial source depot}) \times (\text{Time until item is issued})}{\text{Number of years over which performance is being measured}}$$

The use of these measures is best illustrated by an example:

Data

Five items not filled by initial source depot over 2-year period:

Item A—2-week wait
Item B—4-week wait
Item C—6-week wait
Item D—8-week wait
Item E—10-week wait

$$\text{Average Wait} = \frac{2 + 4 + 6 + 8 + 10}{5} = 6 \text{ weeks/item}$$

$$\text{Item Years of Wait per Year} = \frac{(2/52 + 4/52 + 6/52 + 8/52 + 10/52)}{2 \text{ (years)}} \times 5 \text{ (items)*} = 1.44$$

* Note that this index includes a penalty for both time and number of items.

The average wait index is valueless unless a separate figure is reported for each MILSTRIP priority classification. The second index, item years of wait per year, is of interest only in that it has been used by the Navy in a special inventory model (discussed in ch 13).

g. One of the better measures of performance presently in use is that of average back orders—

Average Back Orders =

$$\frac{\text{Wait while waiting} \times \text{Availability}}{\text{Demand rate}}$$

- (1) *Wait while waiting.* This element is best described as the area under the zero inventory line on the classical sawtooth inventory versus time diagram. Normally expressed as unit-months out-of-stock, it measures both the number of units back-ordered (due-out) and the length of delay before the requisition is filled.
- (2) *Availability.* Perhaps better described as "relative availability," this term represents the fraction of time the inventory status is greater than zero for an individual stocked item. For example, if an item was out-of-stock for 6 weeks during the period of a year, its availability would be—

$$\frac{46}{52} = 0.89.$$

- (3) *Demand rate.* The final term of the average back order index, demand rate, is simply the average yearly demand in units. Dividing by the demand rate expresses the unit-months of units back-ordered in terms of requisitioning volume and permits a rough comparison between items of the relative severity of their back order condition.

h. All of the measures discussed to date have at least four things in common.

- (1) They do not relate performance to program. If a low protection item is out-of-stock, the penalty is as great as for a high protection item.
- (2) Their use is limited to the NICP level.

- (3) They do not measure the performance of the supply system below the NICP level.
- (4) They do not consider the relative criticality of an individual requisition. While MILSTRIP procedures provide a methodology for indicating and responding to supply needs on a basis of their relative criticality, the measures in use do not report performance by essentiality groupings. For instance, it is impossible to tell if supply performance on parts for deadlined end items is better than that for replenishment of stock. Moreover, these measures treat not only all situations but also all items on an equal basis. For example, a requisition for a jeep horn button is just as important under these measures as a requisition for a tank engine.

i. A measure not presently used by NICP's, but one which might be more meaningful than those discussed above, is defined as follows:

% Dollar Demand on Time =

$$\frac{\text{Dollar value of units shipped on time by MILSTRIP standards}}{\text{Dollar value of units demanded}}$$

While still not relating NICP performance to the user's level, this measure would reflect differences in the number of units requested on a requisition, MILSTRIP shipment priorities, and to some extent (by incorporating unit price) the relative importance of shipments demanded and made.

j. To measure the entire logistics system in terms of the service performed for the ultimate user of the weapons systems and support equipment, the measure must take into account the availability of the equipment in the field for performance of their assigned tasks. To do this involves consideration of the maintenance function as well as supply and the introduction of such terms as reliability, maintainability, and availability. The first two terms, reliability and maintainability, lie primarily in the province of the equipment designer and maintenance personnel, and a thorough discussion of them is beyond the scope of this manual. Measures of equipment

availability, however, have direct application to supply management.

k. Two common measures of field performance are—

$$(1) \% \text{ Downtime} = \frac{\text{Number of hours equipment is inoperative}}{\text{Total number of hours}} \times 100$$

$$(2) \% \text{ Availability} = \frac{\text{Number of hours equipment is in use performing its required mission}}{\text{Total number of hours equipment is required for performance of its intended mission}} \times 100$$

The first of these measures, percent downtime, is easily determined and readily available to most field commanders but has the shortcoming of not indicating if the downtime occurred when the equipment was needed or was due to a lack of parts. The second measure overcomes some of these limitations but still does not tell the whole story. For example, a weapon system can rarely be described as being simply operable or inoperable. Between these two extremes there normally exist several levels of degraded operation. The lack of secondary items will frequently affect only a portion of a weapon system, thus reducing its effectiveness although not necessarily rendering it inoperable.

174. System Performance

Research is presently being conducted to develop better measures of system performance. These studies are emphasizing a consideration of both the total system and the effective availability of the supported end item. The present progress of this research is discussed in chapter 11 as it relates to repairable items, in chapter 13 through a review of some of the more advanced inventory models, and in chapter 14 with regard to the use of simulation techniques.

175. Cost Performance

a. In chapter 7 it was stated that the principal inventory costs are those associated with the operation of the supply system (ordering costs), the physical handling of the goods in storage (holding costs), and the inability to fill customer demand (out-of-stock costs). Since these costs interact and are often opposing, performance standards should not be established for each element but, instead, for

the cost of the overall system. For example, a goal for ordering costs should not be fixed at some figure such as \$200/procurement action. Rather, given an ordering and holding cost, a minimum total variable cost can be calculated and performance can be measured as the relative departure from this goal.

b. Though mathematically possible (and even feasible through the use of ADP equipment), total variable cost performance is rarely measured at NIPC's except during special studies, as when new inventory models are being implemented. This apparent management oversight is explained by the fact that different types of funds are involved, and supply management finds it more expedient to control these funds on an individual basis. The development of more sophisticated system-oriented inventory models coupled with more flexible allocation authorities may eliminate this drawback in future years.

c. Several purely financial measures of performance are used by NIPC supply management personnel, but these generally relate to budgetary matters. For example, most NIPC's calculate the ratio of procurement to sales as a measure of the liquidity of the stock fund account. The rate of obligation of available funds is also followed closely on a quarterly basis. These indexes, however, measure only how well the supply activity is doing within a funding constraint and not how effectively they are utilizing the funds expended.

d. Advanced inventory models, however, do consider both cost and performance in the development of their decision rules. For this reason, a method exists for relating cost to service. It is in this context that present-day cost standards should be established.

176. Cost/Service Performance

a. Inventory models may be used at budget development time to determine what funds are required to operate at various levels of protection (service) and, in the course of the fiscal year, whether the performance predicted for the system is actually being achieved. The two model parameters normally adjusted to obtain a desired service level are the safety level and procurement cycle.

b. When other elements of the inventory control model are held constant, the service level is directly related to the size of the variable safety level. The statistical bases for determination of safety levels were discussed

in some detail in chapter 16, where it was shown that the level of protection is related to the demand distribution frequency as measured by a parameter called the standard deviation. The amount of protection, expressed as a percentage chance of not experiencing a stock-out, is measured by the number of standard deviations of demand to be added to the average demand over the procurement lead time. Since the standard deviation and PROLT are constant at any point in time for an individual stocked item, the safety level quantity and protection are a function of a multiplying factor. This relationship is shown as a straight line when plotted on arithmetic probability paper, as has been done in figure 41. The

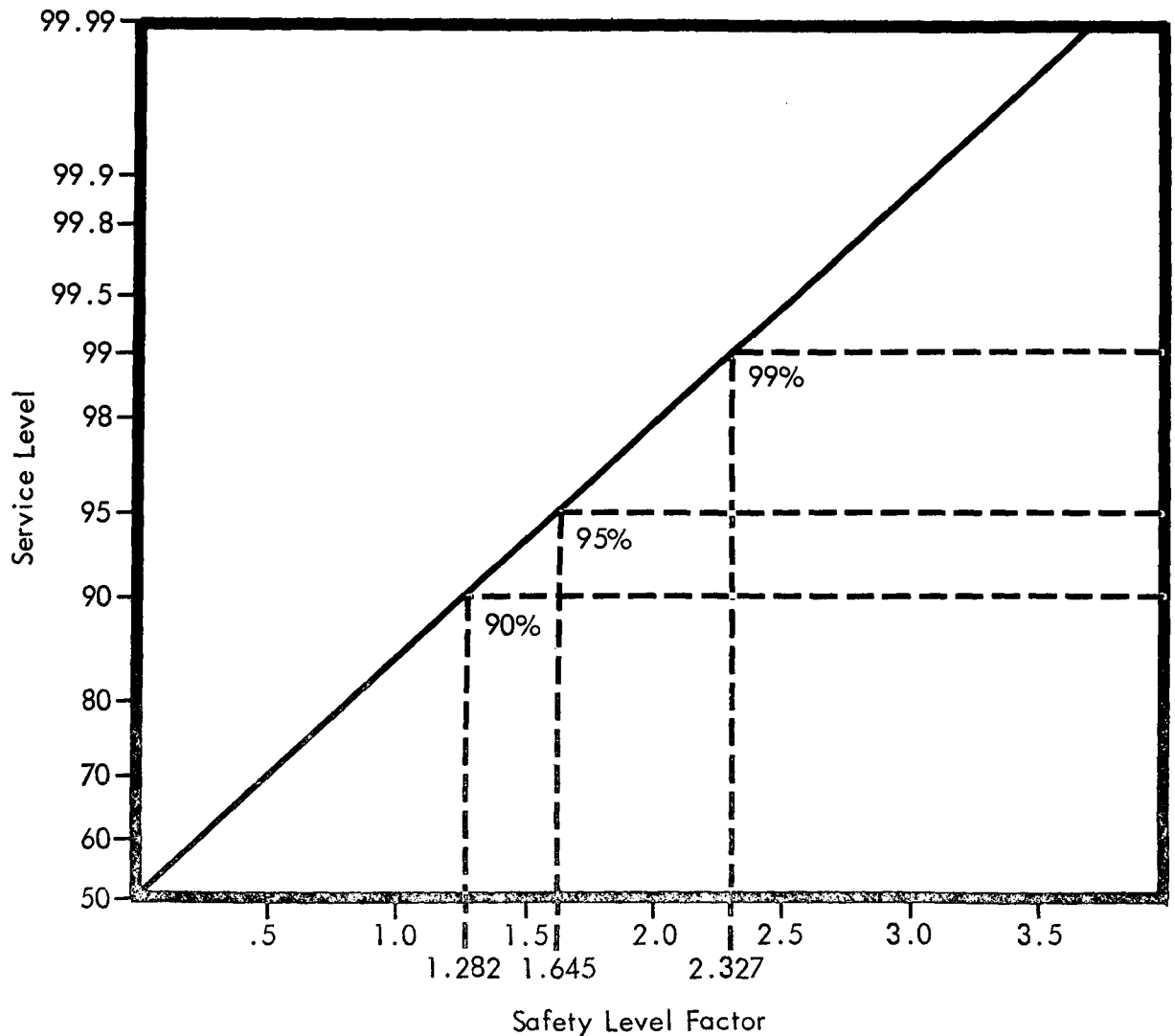


Figure 41. Relationship of safety level to service level.

dashed lines indicate that 1.282, 1.645, and 2.327 standard deviations of demand over lead time are required in the safety level quantity to provide, respectively, 90, 95, and 99 percent protection against stockouts during the PROLT time interval.

c. Figure 41 can be used to calculate the effect on investment in safety level inventories of a change in policy on protection level.

(1) Assumptions and Data

- (a) Uniform protection is provided over PROLT's without regard to variations in the number of procurement cycles per year.
- (b) Present protection level is 95 percent, desired level is 99 percent.
- (c) Total value of current safety level inventory stratification is \$500,000.
- (d) Holding cost rate is 17 percent.

(2) Computation (fig. 66)

- (a) Number of standard deviations for 95 percent protection = 1.645.
- (b) Number of standard deviation for 99 percent protection = 2.327.
- (c) Required safety level inventory stratification for 99 percent protection—

\$500,000 (present SL quantity)

$$\times \frac{2.327}{1.645} = \$707,000.$$

- (d) Procurement funds required on a one-time basis to provide desired protection—

$$\$707,000 - \$500,000 = \$207,000.$$

- (e) Increased annual holding cost—

$$\$207,000 \times .17 = \$35,200/\text{year}.$$

d. The above example is an oversimplification of the actual situation because it fails to consider differences in the number of procurement cycles and lengths of PROLT's for individual items. It will be recalled from chapter 9 that safety levels are used to provide protection only during the lead time period. An accurate estimate of the cost/performance relationship, therefore, can only be obtained by studying stocked items individually or through the use of a statistically valid random sample of the entire catalog of stocked items.

e. Further, since overall inventory costs (personnel, transportation, unit price, interest on capital, etc.) are complex and interrelated, a thorough analysis of cost versus service is a difficult task and is normally feasible only through the use of ADP equipment.

Section III. DEVELOPMENT OF SERVICE/COST CURVES

177. Model Simulation

a. The inventory models used at NICP's to control all LDV items and most MDV and HDV nonrepairable items may be used as tools for budgeting and measuring system performance. The decision rules and parameters for the models have been programmed for ADPS solution, and current asset data is available in the master tape file.

b. Budgetary requirements can be estimated by simulating (ch 14) on the computer the operation of the system for a year or two using actual data (e.g., unit price, lead time, starting assets), forecasted data (e.g., demand), and various operating criteria (e.g., level of protection, procurement cycles).

c. Since it would be very costly to simulate an NICP's entire stockage list (40,000 to 100,000 items) on the computer, a random

sample of five to ten percent of the items may be used instead. If care is taken to insure the representativeness of the sample, accurate data will be obtained that can be easily extrapolated to express the total inventory.

d. It should not be assumed from the above and subsequent discussions that computer assisted cost/performance analyses are simple. They are complex and sensitive. The design of such studies requires the active participation of highly competent mathematicians assigned to the NICP.

178. Total Variable Cost/Service Level Curves

a. The computer simulation can yield, for each of a number of trial levels of performance, such output as—

- (1) Procurement fund requirements.

- (2) Operating fund requirements.
- (3) Changes in procurable levels.
- (4) Changes in inventory stratifications.
- (5) Number of procurement actions.

b. With the above data, it is possible to construct an overall total variable cost/service level curve. Such a curve would resemble that shown in figure 42. Note, in this hypothetical case, the typical relationship of the top few percentage points of improvement in service level being many times more costly than an equivalent amount of improvement further down the scale.

c. With curves of this kind it is possible to obtain good estimates of how much money would be required to operate at a desired level of protection against stockouts. On the other hand, for a given budgetary constraint, it is possible to determine an imputed level of protection.

d. The analysis described above may be expanded to provide more specific information. It would, for example, be possible to divide sample items into several classifications of essentiality and to develop curves for each group. In this manner a higher level of protection and better performance could be obtained for combat essential items within a fixed budgetary limitation.

e. Another way of considering budgetary restrictions in the performance of a model is to use the technique of Lagrangian multipliers or some variation of this. Lagrangian multipliers are frequently applied in operations research studies, but a discussion of them is beyond the scope of this manual.

179. Procurement Cycle Curves

a. Calculation of an EOQ fixes the optimum procurement cycle for items controlled on this

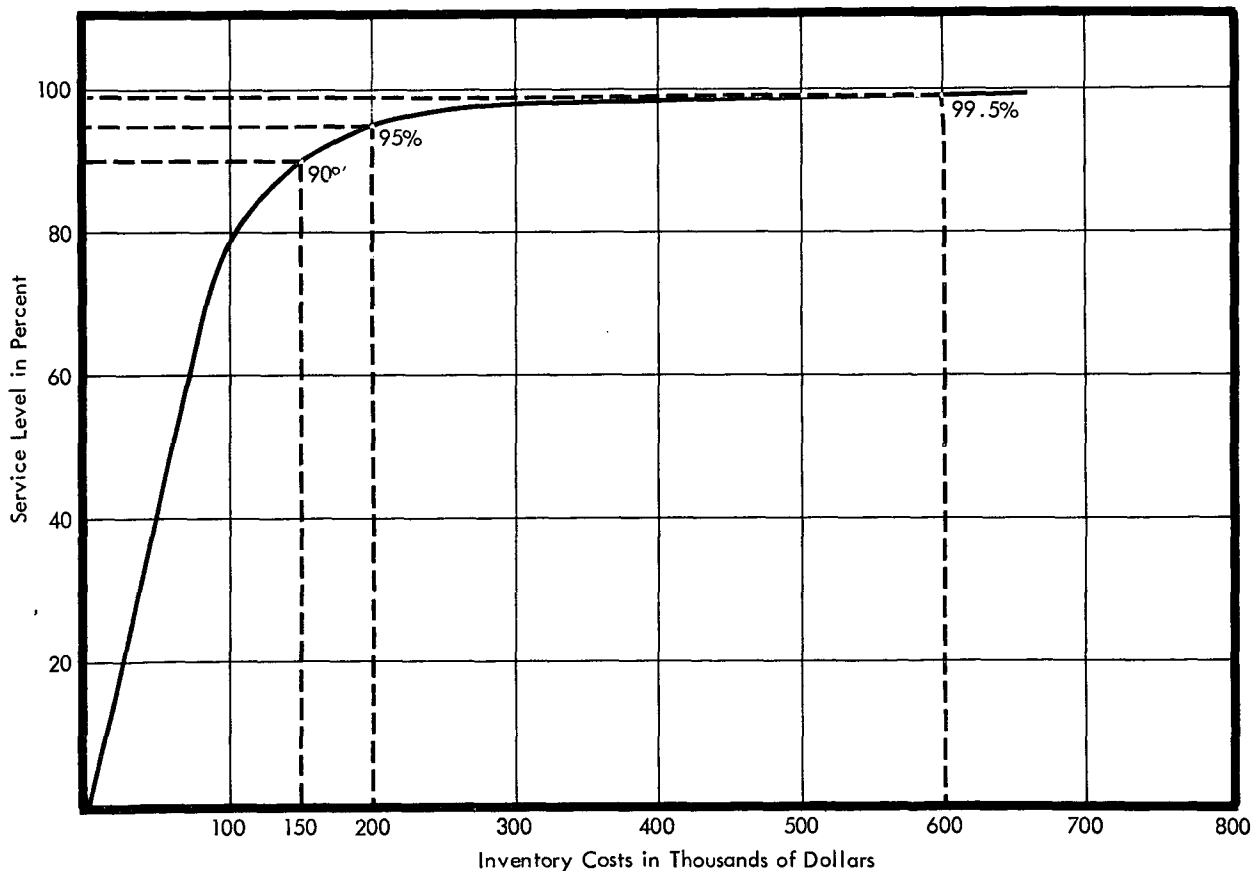


Figure 42. Total variable cost/service level curve.

basis. If procurement funds are constrained, however, it may be desirable to deviate from the optimal cost policy and reduce short-term funding requirements by increasing the frequency of procurement.

b. By running the above computer program with varying fixed procurement cycles (ignoring the EOQ calculations), curves of the variety illustrated in figure 43 can be developed. These data may then be used to evaluate various combinations of operating policies within the allotted funds. The "number of procurement actions" curves are required to measure the effect on the work load of the procurement activity. It should be recognized, however, that purposeful departure from EOQ quantities will increase total variable costs in the long run.

180. Other Uses of ADPS in Performance Measurement

a. The NICP automatic data processing system can provide other valuable data as an aid to performance measurement in addition to the model simulations described above.

b. Most NICP's receive periodic reports on lines out-of-stock, number of procurement actions initiated, value of procurement actions initiated, and similar information as output from ADPS. These reports furnish data on budgetary status and supply performance but can also be used to determine if the inventory models in use are functioning as they were designed to do. AR 710-45 recommends the periodic comparison of forecasted demand rates with those actually experienced, but few NICP's are making these comparisons routinely and none are using their ADP models to assist in this analysis. If, for example, the model incorporates variable safety levels selected to provide a 95 percent protection against stockout (5 percent stockouts) and, instead, stockouts are actually running at a level of 10 percent, the system can be judged to be out of control. In this case the demand forecasting system should be investigated and consideration given to the use of improved data smoothing techniques.

c. Inventory managers should not, however, be surprised if models do not always perform

as designed. Sound logical explanations exist for this apparent abnormality.

- (1) Real life logistics systems are always more complex than their mathematical models. A sensitive parameter may have been overlooked in the model's design.
- (2) Models take time to develop, program, and implement. In the meantime the system has remained dynamic. Customer's ordering habits may have changed because, for example, of a changeover to the Command Stock Fund.

d. One NICP initiated a contracted study during the period 1961-63 directed toward the development of a standardized performance and evaluation report. The report was to be generated by ADP equipment and issued quarterly. Further, this report was to present, on a single page, the following actual versus goal information by commodity groups;

- (1) System supply availability
- (2) Demand forecasting accuracy
- (3) Procurement lead times
- (4) Inventory holding costs.
- (5) Supply action costs

The study was terminated prior to completion when MILSTRIP was introduced with accompanying changes in procedures. Preliminary findings were of general interest, however, in that they indicated that such a report would reveal significant differences in service performance between commodity groups, which, in turn, could be traced to poor estimates of demand or procurement lead time. On the basis of this study, it is apparent that further work needs to be done to close the feedback loop between supply control study forecasts and actual experience.

e. Inventory models and performance standards will change as more research on the logistics system is accomplished and as more flexible, higher-speed ADP equipment becomes available. This chapter has presented some examples of present standards and performance evaluation techniques. Those pertinent to particular operations should be used, but continuing improvement in methodology and application should be expected and achieved.

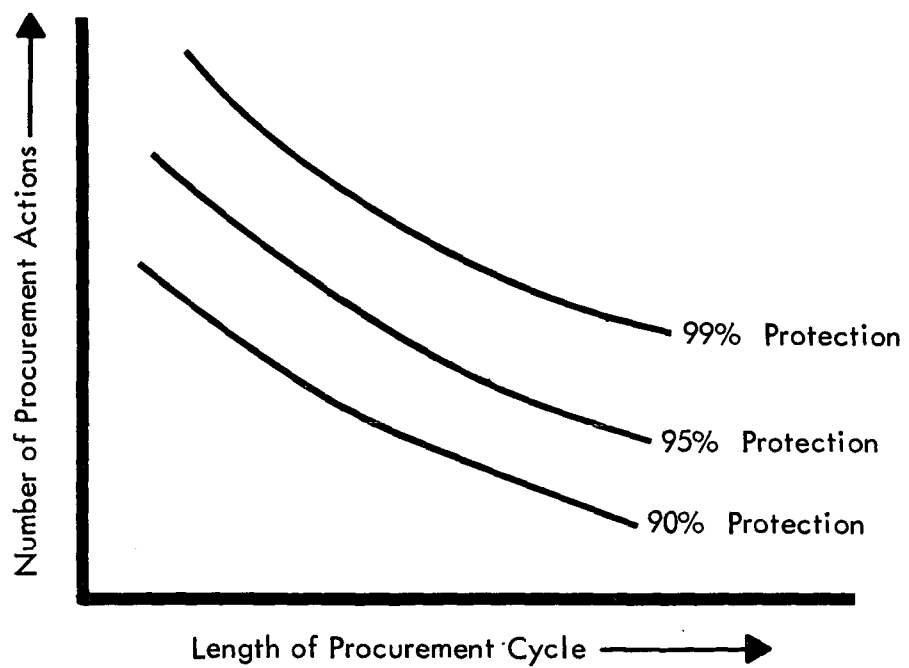
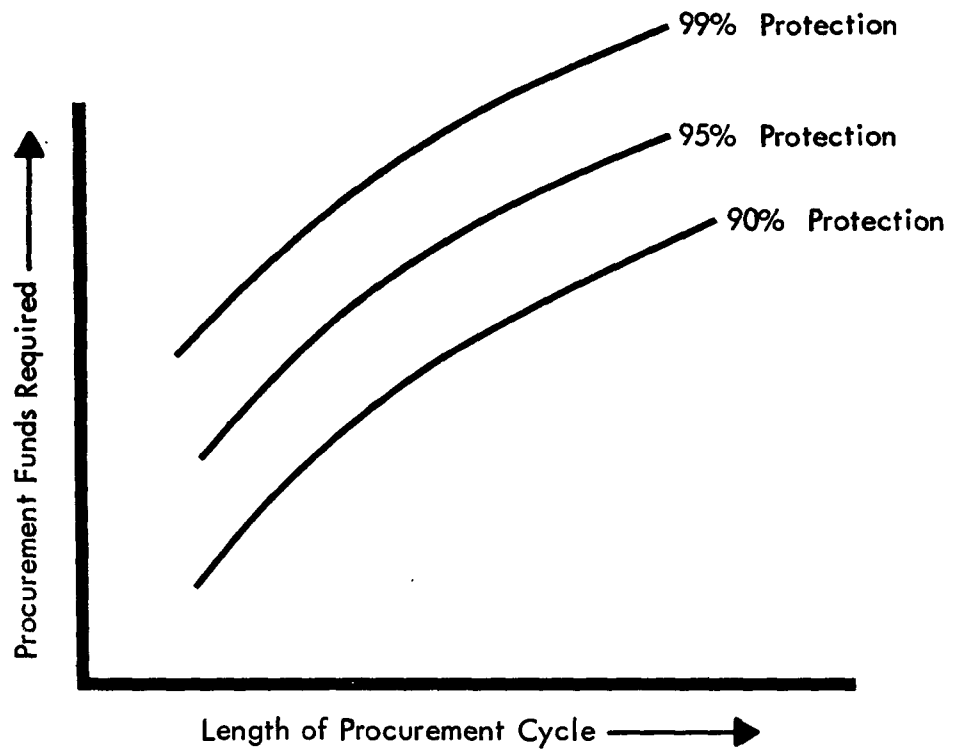


Figure 43. Effect of procurement cycle length on funding requirements and number of procurement actions.

CHAPTER 13

SUPPLY CONTROL SYSTEMS

Section I. GENERAL

181. General Objectives

a. Several mathematically-based inventory control models have been developed by government agencies and private contractors for the management of secondary items. Five important examples of these models will be discussed here. While these systems introduce varying degrees of mathematical sophistication in their approaches, all of them have the following general objectives in common:

- (1) To furnish items to using organizations on demand with a high level of performance.
- (2) To minimize overall inventory investment within the limits imposed by the first objective.
- (3) To minimize the cost of operating the supply system, particularly those costs associated with replenishment actions.

b. As mentioned above, each of these systems offers a different approach to the attainment of these objectives. This chapter is primarily devoted to describing and analyzing the significance of these differences. For this reason, the similarities of these systems will only be touched upon, and any procedures not mentioned should be assumed to be common to all.

c. All Army NICP's use one of the first two systems, either the M.I.T. or the Harbridge House model. Because of the general familiarity with these systems, more detail is provided on the remaining three models.

182. Criteria of Comparison

a. Each system will be described in terms of the following characteristics:

- (1) Specific objectives.

- (2) Measures of performance.
- (3) Factors considered.
- (4) Assumptions made.

b. Since inventory management is not yet an exact science, the assumptions made in each system are of particular importance. In this analysis of these models, the general validity of each assumption is examined. It should be noted, however, that two differing assumptions can frequently be defended on the basis of peculiarities of the individual items included in the original studies. For this reason, models may differ in their relative applicability to broad classifications of supply items. Though each of these systems was designed as a complete entity, particular parts of each system can often be used effectively for small groups of items when implementation of the complete system is not feasible. For instance, the variable safety level concept can be used apart from the rest of a particular system.

c. The purpose here is not to evaluate and rate these systems according to their relative effectiveness; rather, the purpose is to point out their differences and leave the final analysis of the applicability of each model to the individual NICP's. At the present time, it is unlikely that any one supply control system could best meet the requirements of all items of all NICP's. Differences in demand characteristics, distribution policies, maintenance practices, and funding capabilities that exist between items and between Commodity Commands should in turn be reflected in the application of a variety of control models.

d. Several reasons exist for not standardizing one model at this time. The primary reason is that the performance of the models in actual practice has not yet been determined. In addi-

tion, no one model fits the problems of all NICP's. Another reason is the inability of

current models to handle adequately the unique problem posed by repairable items.

Section II. FIRST SYSTEM (M.I.T.)

183. Specific Objective

Within the framework of the general objectives already discussed, this system has as its specific objective the maintenance of a specified level of national availability while satisfying customer demands. To accomplish this objective, safety levels are computed for each item according to its statistical variability of demand. The implementation reports also recommend that reliability of supply, mission of the supported activities, and military essentiality of the item should be considered when establishing safety levels. Since the variability of demand is the only mathematical criterion used for determining safety level, a large part of the ensuing discussion will be devoted to explaining how this variability is handled.

184. Measure of Performance

The measure of performance in this system is national availability expressed as a percentage of time "in" stock (or conversely, percentage of time out-of-stock at) CONUS depots. Stated in another way, the system is said to be in-stock "X" percent of the time. Thus, if the level of service performance is established as 95 percent, then the system will be out-of-stock only 5 percent of the time. This level of performance should not be set arbitrarily. For instance, budgetary considerations will frequently constrain the level of service performance that can be attained. It was shown in chapter 12 that it is possible to use the control model to simulate a wide range of performance levels that may be attained within a given budgetary restriction.

185. Factors Considered

a. Several important factors used to handle demand variability must be discussed before this system is described further. The first factor is average yearly demand (AYD), which may be forecasted for the future study period by one of the techniques described in chapter

5. The second factor is unit price (*UP*), which can vary from one ordering period to the next but, when used in a supply control study, should be the expected price of the next procurement action. By knowing or being able to estimate these two factors, demand variance can be estimated by a relationship that generally exists among an item's annual demand, its unit price, and the demand variance. This relationship is known as the variance-to-mean ratio (*VMR*). Since a thorough discussion of the derivation of *VMR* appears in chapter 9, only a brief explanation is provided in the next paragraph.

b. Assuming that the demand distribution, as described by its order frequency and order size, approximately follows the compound Poisson distribution (chapter 16), then

$$VMR = \frac{E(S^2)}{E(S)}.$$

This expression means that the *VMR* is the ratio of the average of the squares of order sizes to the average order size. This relationship can be conveniently plotted on a nomograph in such a way that, knowing *AYD* and *UP*, the *VMR* can be directly determined. Then, knowing the *VMR*, the safety level and reorder quantity can then be easily computed as described in chapter 9.

c. Another factor that is important in this system is the forecast of procurement lead time. To avoid mathematical complexities, this system treats *PROLT*'s as constant. Another reason for assuming constant *PROLT*'s is that the expense of maintaining comprehensive *PROLT* records and calculating combined variabilities is rarely justifiable on the basis of obtainable model improvements. For this reason, if the procurement lead time is indeed variable, the system may encounter difficulty in meeting an in-stock performance objective. When *PROLT*'s are variable, the selection of the maximum value will result in a more conservative statement of safety level.

d. This model recognizes the relationship existing between reorder quantity and safety level in its determination of reorder cycle quantities. This relationship is explained and demonstrated graphically in chapter 9. It should be understood, however, that the safety level feature can be used without a determination of the *EOQ*.

186. Assumptions Made

The major simplifying assumption made during the development of this system is that the demand distribution of secondary items at the national level approximately follows the compound Poisson distribution. Before this assumption was made, a selected sample of 50

items was tested to determine which of the "classical" distributions, if any, their demand pattern resembled. This study showed that the compound Poisson most closely described the sample data. This result was not totally unexpected, as the compound Poisson is a very general distribution and can therefore be made to fit a wide variety of demand patterns. An additional reason for initially suspecting the compound Poisson is that Poisson processes frequently are used to describe time-dependent variables. Therefore, unless additional research on a larger sample of representative supply items disproves the general applicability of the compound Poisson distribution, this assumption appears to be well founded in theory and proven by analysis.

Section III. SECOND SYSTEM (HARBRIDGE HOUSE)

187. Specific Objective

As was true for the first system, this system has as its specific objective the maintenance of a particular performance objective while minimizing total cost and satisfying customer demands. Again, the performance objective criterion is also used, rather than at-

tempting to assign a dollar cost penalty to an out-of-stock condition.

188. Measure of Performance

The measure of performance used in this system is the percentage of customer requisitions satisfied out of the total number of requisitions received—

$$\text{Performance} = \frac{\text{Number of customer requisitions satisfied}}{\text{Total number of requisitions received}} \times 100$$

The requisitions referred to are those received by the NICP's. The reason for this choice of performance measure will be clear as the rest of the procedures of this system are explained.

189. Factors Considered

Like the first system, this system conforms to the general mathematically-based concepts of inventory management. It does, however, base its development of the reorder point quantity on a separate consideration of "safety level" and "order and ship time" quantities. Economic order quantities are computed as described in chapter 8. While this system makes use of variable safety levels, it does so for groups of items rather than for each item on an individual basis. Another difference between this and the earlier system lies in the values used for costs of ordering.

190. Assumptions Made

a. This system assumes that the frequency of demand follows the incomplete gamma distribution. It does not consider variability in order size but instead assumes that every order is of the same size. Thus, 95 percent level of protection in this system assumes that, to actually achieve this performance, 95 percent of the demands during lead time will be less than or equal to the average number of lead time demands.

b. This system does not take into account the interrelationship between safety level and reorder quantity. An item ordered monthly would be subject to a stockout 12 times as often as an item ordered annually. Therefore, a 95 percent performance level for this system might reduce to something less than 95 percent if the item is ordered more frequently.

c. This system has the advantages of being easily explained and being implemented on a manual basis. It will, on the average, require smaller safety level quantities which, in turn, will provide less protection but at a reduced requirement for investment in inventory. It

incorporates the desirable features of economic order quantities and variable safety levels and, if order quantities are not extremely variable, can be expected to perform adequately.

Section IV. THIRD SYSTEM (PLANNING RESEARCH CORPORATION) (PRC)

191. Specific Objectives

This system is used primarily for the supply control of initial provisioning and repair parts for the POLARIS Fleet Ballistic Missile System. It is currently being extended to the determination of allowance requirements for parts for other ships in the fleet. Its specific objectives are twofold:

a. The first objective is to determine which repair parts, and how many of each, the POLARIS submarines should carry during cruises of various lengths. This objective deals with the situation of cruise conditions during which replenishment is impossible.

b. The second objective is to determine the optimal reorder points and reorder quantities for each of the stockage points in the system that can obtain resupply when the reorder point is reached. This objective applies to shore facilities and repair tenders not subject to the replenishment restriction imposed upon a ship at sea.

192. Measure of Performance

This system does not have a measure of performance that can be directly expressed in terms of levels of protection as did the first two systems.

a. To satisfy the first objective, the *expected number of shortages is minimized*, subject to the volume constraint imposed by the available storage capacity, with each shortage weighted according to item essentiality (para 193a).

b. To satisfy the second objective, the *shortage cost is determined*, then the *reorder quantity that minimizes total cost* is determined, where

$$\begin{aligned}\text{Total Variable Cost/Year} = & (\text{Annual Cost of} \\ & \text{Reorders}) \\ & + (\text{Annual} \\ & \text{Holding Cost}) \\ & + (\text{Annual} \\ & \text{Shortage Cost})\end{aligned}$$

The reorder quantity is then used to find the associated reorder point (para 193b).

193. Factors Considered

a. The first objective (para 192a) considers the following factors:

- (1) Probability that an item will be demanded "X" times during a cruise, where $X = 1, 2, 3, \dots n$.
- (2) Essentiality of the item.
- (3) Space required to store the item.
- (4) Total space available for storage.

The parts to be stocked during the cruise and the quantity of each to be carried are then determined by minimizing the expected number of shortages, subject to the volume constraint, with each shortage weighted by the essentiality of the part.

b. The second objective (para 192b) considers the following factors.

- (1) Average demand.
- (2) Demand variability.
- (3) Resupply time.
- (4) Holding cost at the activity.
- (5) Normal reorder cost.
- (6) Emergency reorder cost.
- (7) Shortage cost.

Shortage cost is of particular interest because, in this model, an actual dollar value penalty is estimated by determining the next higher assembly that would be rendered partially or totally inoperable for lack of a part. A cost penalty per unit shortage is then charged

that is equivalent to the cost of the next higher assembly amortized over its expected useful life.

194. Assumptions

Several assumptions are made in this system regarding the statistical distribution of demand over lead time. The three distributions mentioned here are described in more detail in chapter 16.

a. If the forecasted annual demand for a part is between zero and two, the *Poisson* distribution is assumed.

b. If the forecasted annual demand lies between two and one hundred, and the variance-to-mean ratio of demand over lead time is greater than one, the *Negative Binomial* distribution is assumed.

c. If the forecasted annual demand is greater than one hundred, or if it lies between two

and one hundred and the variance-to-mean ratio of demand over lead time is less than or equal to one, than the *Normal* distribution is assumed.

195. The Repairables Situation

This model also handles repairables, although not in an optimal way. If an item is continually repaired, then a repair set-up cost is estimated. This cost takes the place of reorder cost in the preceding formula (para 192b) and the optimal repair batch size and repair initiation point are computed in the same way as the reorder quantity and reorder point were computed above. If not all items issued are repaired, the optimal repair batch size formula is applied to that fraction of the demand that is later returned as repairable, and the optimal procurement quantity formula is applied to the balance of the requirement.

Section V. FOURTH SYSTEM (DSA)

196. Specific Objective

The system discussed in this section is a system currently being implemented by DSA. The objective of the DSA system is consistent with the general objectives stated previously—the satisfaction of customer demands at minimum cost. A further objective in the implementation of this system is to achieve maximum desirable standardization of procedures among all operational elements of DSA. The

extent to which this objective will be achieved has yet to be determined.

197. Measure of Performance

The measure of performance used in the DSA simulation model is “percentage of demands filled without back order.” This measure assumes that all demands are eventually filled and gives credit for partially filled demands (e.g., if demand is 100, but only 75 can be issued, percent fill is 75 percent).

$$\text{Performance} = \frac{\text{Number of units demanded and filled}}{\text{Total number of units demanded}} \times 100.$$

198. Factors Considered

a. This system involves the computation of most of the commonly used operating parameters, such as *EOQ*, variable safety level, and reorder point. Slight differences exist, however, between the details of DSA’s computational procedure and that incorporated in the M.I.T. and Harbridge House models.

b. A single constant for each of the low and high value demand groups is computed by each Center based upon that Center’s variable costs to order and hold. For low value demand items, the costs to order are based on informal pro-

curement costs, while, for high value demand items, the costs to order are based on formal procurement costs. The following form of the *EOQ* formula is used:

$$EOQ = K \sqrt{\frac{Y}{U}} \quad \text{where } K = \sqrt{\frac{2C}{H}}$$

where

EOQ = economic order quantity

Y = annual dollar demand

U = unit price

C = ordering cost

H = holding cost (as a percent of inventory value).

c. The following procedure is used to compute variable safety levels (*VSL*). The service function *VSL* is described as

$$f(k) = \frac{Q}{MAD} (1 - P)$$

where

f(k) = the service function for a normal distribution of forecast errors. Tables have been developed that convert service functions to variable safety factors (*k*).

k = variable safety factor

Q = order quantity in units

P = desired percentage of stock availability expressed as a decimal

MAD = Mean Absolute Deviation of forecast errors during procurement lead time. (A discussion of *MAD* appears in ch 5)

then,

$$VSL = k (MAD).$$

199. Important Differences

a. This system defines levels of inventory stratification in a slightly different manner than the method used in the Army. The three selective management groups of this system are—

- (1) Low value demand items—items having a procurement cycle of more than 12 months. They may be replenishable or numeric stock objective type.*
- (2) High value demand items—items having a procurement cycle of 12 months or less regardless of the value of the annual demand.
- (3) Very important program (VIP) items—items selected by a Center for intensive management because of their high essentiality to a particular mission or weapon system, their extreme-

* Numeric stockage objective—a stockage objective used in lieu of a regular procurement objective because the item experiences too few units of demand to be managed on a replenishable demand basis.

ly high dollar value or other similar importance.

b. It should also be noted that this system provides for the use of three types of safety levels.

- (1) Fixed for items that cannot be forecasted based on replenishable demand.
- (2) Emergency level when appropriate.
- (3) Service function variable safety level for replenishable demand type items.

200. Forecasting Procedures and Assumptions

a. The procedures used to forecast requirements for replenishable demand type items are as follows:

- (1) Use historical demand data as a base.
- (2) Use double exponential smoothing in the computation of the system forecast.
- (3) Use single exponential smoothing (ch 5) in the computation of storage point forecasts as a basis for the establishment of levels for distribution of stock.
- (4) Use alpha factors that correspond to the demand characteristics of the items managed and the forecast frequency.
- (5) Provide for the use of program change factors and additives (special program requirements) as required.
- (6) Provide for the use of tracking signals at the option of each Center.
- (7) Provide for annual forecasts of low value demand items.
- (8) Provide for quarterly forecasts of high value demand items.
- (9) Provide for forecasts of VIP items more frequently than quarterly.
- (10) Consolidate recurring and nonrecurring demand as a basis for forecasting low value demand items.

b. It should be noted that in determining variable safety levels, the assumption is made that forecast errors are normally distributed.

Section VI. FIFTH SYSTEM (AMMIP)

201. General

This system is an example of a very special management system tailored to the characteris-

tics of a particular group of items. It is included in this manual because of the long-range possibility of extending the provisions of this

system to other commodity groups when more and better consumption data become available.

202. Specific Objective

This system is designed to improve the management of aviation materiel by improving methods of accumulation, reporting, and analysis of worldwide aviation maintenance data. It is somewhat different from the systems discussed earlier in content and scope in that it restricts itself to the management of repairable items for which detailed operating and maintenance data are available (aviation parts). It is also different in that it is only a two-level system that considers worldwide stocks and decides how to distribute them between the NICP system and the user system for best performance. This system incorporates the Aircraft Component Reporting System (ACRS) into the TAERS reporting system.

203. Measure of Performance

a. The measure of performance used in this system is "waiting time for replacement items." This performance measure is used in two different ways.

- (1) An inventory level required to achieve a specified level of customer service can be computed or, conversely,
- (2) The customer service that can be attained with a given amount of total inventory can be computed.

The first of these is the procedure used in the previously discussed systems, where an inventory level is determined that provides a desired level of performance.

b. More specifically, these two procedures would be used as follows:

- (1) Given the circumstances under which the system is projected to operate after the initial provisioning phase has been completed, and after failure rates have been stabilized at an expected MAOT (maximum allowable operating time), compute the desired inventory level. For this computation it is necessary to agree upon a desired level of customer service expressed in terms of the time a removing organi-

zation has to wait, on the average, to obtain a replacement item.

- (2) Given the circumstances under which the system is now operating, compute the best level of customer service that can be obtained with the current total inventory. The combination of field and national inventory levels resulting in the shortest average waiting time is a byproduct of these computations.

204. Factors Considered

This system considers for each geographic area the forecasted removal rate, shipping time for serviceable items, local repair lead time, and the fraction of all removals repaired locally. Furthermore, it considers the average cycle time for the entire system defined as the time from removal for overhaul to completion of overhaul (consisting of the shipping times from user areas to overhaul facilities for unserviceables, the time lost awaiting overhaul, and the time spent in overhaul).

205. The Forecasting Procedure

a. The forecasting problem presented by the items controlled by this system is somewhat unique, because for aircraft parts there is a closer correlation between actual item life and the requisitions received for the item than there is for other classes of items. This is in large measure due to the records of hours-of-operation required for many aircraft components.

b. A forecasting method frequently used in this system is the so-called actuarial method developed by the Air Force. The first step in this method is the computation of the survival probability curve, which describes, for each flying hour age, the fraction of all items that survives this age without removal. (See ch 13 on reliability estimates.) The actuarial program requires—

- (1) The age of items at the beginning of the preceding year, or at the time of installation if installed during the preceding year.
- (2) The age of items at the time of removal, or at the end of the preceding year if not removed.

c. The second step is the computation of the expected number of removals in the forecast

period, given a certain flying hour program. In addition to the computed survival probabilities, this step requires the ages of currently installed items as well as the average age of the items in the supply system with which these installed items are to be replaced if they are removed.

206. Accuracy of the Actuarial Approach

a. The actuarial approach should produce a more accurate forecast than can be obtained from single value predictors, such as the previous year's removals or the observed average

hours of operation between removals. The greater accuracy of the actuarial forecast is the result of—

- (1) Using an age-dependent failure rate estimated from observed removals, but also considering those items that have survived without failure.
- (2) A consideration of the present age of the items in the system.

b. Good correlation between forecasted and actual survivability rates has been obtained in tests with actual usage data.

CHAPTER 14

RESEARCH SIMULATION SYSTEMS

Section I. DESCRIPTION AND PURPOSE OF SIMULATION

207. Definition

a. Simulation, in the context of this chapter, is defined as the act of reproducing phenomena under conditions conducive to study yet retaining the pertinent characteristics likely to occur in actual performance. These characteristics may be represented in a model either symbolically or physically.

b. The most familiar simulations are those that reproduce, on a reduced scale, a part of the physical world. The simplest example is a model train set. Also, model cities are often constructed to study or demonstrate concepts and designs during urban redevelopment planning. Another example of simulation of physical characteristics is the conditioning of astronauts for space travel. This is accomplished by simulating in a laboratory the conditions found in outer space.

c. Analytical simulation is mathematically more complex than simple model simulation but follows the same principles. In these cases, the real situation is reduced to a series of mathematical equations instead of to a physical model. By varying the input data and the parameters of the system, the impact of variations likely to occur in real life can be studied and analyzed with ease and completeness.

d. One of the most valuable simulation tools is the electronic computer. ADP equipment can be programed to simulate complicated information flow or mechanical systems on an accelerated basis. Moreover, complex man-machine simulations that contain analysis and feedback loops that permit the testing of a variety of decision rules can be performed in the computer.

208. Advantages

a. Simulation provides an avenue for evaluating new management policies and techniques that may or may not have adverse effects if applied to an existing system. By simulating the operation, the application of new concepts can be studied with a minimum of risk to the functioning system. In the area of supply management, simulation can be used to test new methods of forecasting, stocking, or distribution without disrupting day-to-day operations. In this manner, management can evaluate the effect of proposed changes on performance and costs prior to making commitments.

b. The operation of an entire business over a period of several years can be simulated on a computer in a matter of minutes. As a result, significant trends or the potential effects of proposed modifications in operating policies or procedures can be studied in detail before implementation or before actual feedback data are available.

c. Simulation can be employed as a training technique. A system may be studied in a classroom environment by exercising a computerized model of the operating system. Students may test decision rules in the computer, thereby accelerating their grasp of course material and providing the instructor with a measure of their comprehension of system principles.

d. A type of simulation known as "gaming" permits analysis of competitive situations where two or more antagonists have independent choices of action. Through use of a computer, evaluation may be made of the complex interaction of decisions across time. In many gaming applications, the result of each inter-

action provides the basis for the next set of decisions.

e. In most ADP applications the bulk of the computer running time is devoted to routine, repetitive operations. Only a small portion of the input data calls for the use of special treatments (routines). For this reason, when programing improvements are proposed for an ADP operation, it is often desirable to test the new programs on a prepared data mix which will emphasize the special treatments. By so doing, it is possible to simulate the ADP operation and conserve valuable computer time.

f. Finally, utilization of the simulation technique can provide answers to problems incapable of analytical solution. By employing Monte Carlo techniques to situations where various outcomes have different deterministic chances of occurrence, future events can be estimated and studied. Monte Carlo techniques employ random numbers in determining a probabilistic quantity. If data can be fitted to a known frequency distribution with definable parameters, simulation can provide accurate estimates of how this data will occur in the real world situation over a long period of time.

209. Disadvantages

a. It should not be concluded from the above discussion that simulation techniques offer a panacea for the solution of all complex analytical problems. The limitations of this technique should also be recognized.

b. It is often difficult to describe the real world in a mathematical model with sufficient accuracy to yield useful results. If the differences between two hypothesized systems are expected to be small, simulation would probably not prove to be a satisfactory evaluation technique. Unfortunately, this limitation, the relative sensitivity of the model to varied input data, is frequently not apparent until after significant amounts of time and money have been expended for analyses and computer programing.

c. Studies involving the use of computerized simulation models are normally expensive. Although this cost may be small relative to

the potential savings that may be identified, or the loss that might be experienced by applying an untested technique to a real situation, it will nonetheless usually represent a significant out-of-pocket expense.

d. The system that is simulated through the use of a model will, in most cases, be ultimately implemented by humans. It is difficult, if not impossible, to anticipate human judgmental decisions (both good and bad) with sufficient reliability to permit their incorporation into the model. If decision rules are clear-cut (or, in two competing systems, of comparable complexity), this limitation may not be restrictive. However, the possible effects of human intervention on the prospective system should be evaluated before a simulation approach is selected.

210. Simple Simulation Examples

a. Examples can best illustrate the ability of simulation to solve problems that cannot be analytically resolved. The general approach is to reproduce the real situation in miniature for the purpose of studying characteristics impossible or impractical to isolate in the real world.

- (1) The Navy's David Taylor Model Basin, in Washington, D.C., simulates the resistance and seaworthiness of oceangoing craft by towing scale models of ships in a towing basin.
- (2) The simulation of various air currents on a new aircraft through the use of a wind tunnel is another familiar example.

b. An example of a working simulation model is a chemical pilot plant that can be operated for a detailed analysis of plant processes prior to actual construction of the full-size plant. In this way, the pilot plant assists in the detection and resolution of problems that would be extremely expensive if experienced in the actual plant after start-up.

c. An analytical simulation example can be drawn from the petroleum industry. The technique of linear programming is used to determine the optimal fractionation ratios for the crude oil based upon current market prices for numerous possible derivatives.

d. The generic term simulation suggest to many a principal technique, a computer simulation. The emphasis afforded the computer in simulation efforts is valid. The majority of recent significant applications of the simulation technique have been partially or wholly dependent on the computer's capabilities.

- (1) Many gaming computer simulations can be cited. An example is a business situation programmed into the machine where alternative decisions are available. The simulation provides results based on the alternative decisions supplied to it.
- (2) Research simulations are another group. An example can be drawn from the operations research field.

Arrival and service times at toll gates or check-out stands have been simulated through application of queuing techniques.

- (3) As discussed in paragraphs 212 and 213, a great deal of logistics research has been based on application of simulation techniques.

211. Summary

Computer simulation and gaming have developed rapidly since about 1951. However, just as the electronic computer is in its infancy, so is the field of simulation. Nonetheless, simulations of logistics systems have provided solutions to real problems, as will be shown in the next section.

Section II. EXAMPLES OF SIMULATION IN THE LOGISTICS FIELD

212. Gaming

a. CALOGSIM (Computer Assisted Logistics Simulation), developed at the U.S. Army Logistics Management Center, Fort Lee, Va., is a computer simulation of the supply management activities of a typical NICP. In the CALOGSIM model, a representative sample of USAMC inventory, including principal and secondary items, is manipulated in an idealized (simplified) situation.

- (1) The CALOGSIM model is used to train military and civilian personnel in the operation of the Army logistics system at the NICP (wholesale) level. Its use enables the students to make decisions based on past experience or instruction and then to observe the results of these decisions over sequential time periods.
- (2) The model utilizes selective management and management by exception techniques and is designed to integrate the major functional areas of the logistics system—thereby affording the student a realization of their interactions and complexities.

b. The Research Analysis Corporation (RAC) games are examples of models being used for the study of both U.S. Army supply and management systems. These games were developed for two reasons—first, to facilitate

study of the capability of the supply system to provide for the increasing demand in the coming years; second, to develop improved management and information systems for projected operations. These games have been designed to permit evaluation of current problems rather than for basic research. Therefore, specific problems, such as number of supply items which can be feasibly managed, are being analyzed.

213. Problem Research Simulations

a. While it is a relatively new technique, simulation has had many practical applications to real life logistics systems that have yielded meaningful, useful information. A brief summary of several significant examples is presented below to illustrate this point.

b. Examples—

- (1) The U.S. Air Force in cooperation with a prominent research organization has simulated two logistics systems in order to assess their relative performance and cost. The “proposed” system was found to cost about one-half as much in total inventory investment as the “operational” system at an equivalent performance level, measured in terms of stockouts. The study demonstrated that the effectiveness and cost of an

existing system could be measured against a hypothesized system by using simulation techniques.

- (2) In another simulation, also for the Air Force, a centralized inventory control system was measured against other control policies. By having centralized inventory information, the new system made more effective use of available data, thus, resulting in more uniform distribution, relative to demand, of available resources.
- (3) The Navy's Bureau of Supplies and Accounts (BUSANDA) in which coordination with industry has endeavored to determine which, when, and how many spares to order to maintain a specified level of system performance at a minimum cost. This model minimized provisioning costs for a required level of performance over a specified period. Simulation of this model revealed its sensitivity to estimates of future demands. The

main conclusion derived from the use of this dynamic provisioning and reorder model was the need to calculate provisioning requirements incrementally as historical demand data became available rather than to provision all at one time.

- (4) The AMC Inventory Research Field Office at Frankfort Arsenal has conducted several studies of Army supply management procedures using simulation techniques and is continuing with research in this area. Examples of some of their current work on multi-echelon effects are presented in chapter 18.
- (5) The Harbridge House and M.I.T. inventory control models were both tested on computers, using simulation techniques, prior to their implementation. These studies were used to compare the costs and performance of the proposed model against the existing supply management system.

Section III. COMPELS

214. Introduction

The examples of simulations presented in paragraphs 212 and 213 were generally limited in scope to one area of the logistics system. The logistics system is complex, however, and the overall efficiency and effectiveness of the system is, to a large degree, a function of interactions that occur among its elements. Therefore, to avoid suboptimization, it is necessary to consider the entire system.

215. Development

a. A project is currently in progress at the U.S. Army Logistics Management Center (USALMC), Fort Lee, Va., which has the aim of developing a series of integrated models of the Army wholesale logistics system. In this manner, COMPELS (Computerized Evaluation of the Logistics System) is expected to overcome the limitations and disadvantages of the earlier models that treated only elements or parts of the system.

b. The COMPELS model covers the full spectrum of business administration and management of the resources required to develop, supply, and control services and commodities to the Army-in-the-field. Thus, the model considers not only inventories but also the availability of funds for logistics services and commodities, the research and development necessary to introduce those commodities and services, and the control of intangibles, including both working capital and organization. Finally, the model is designed to provide a key to the understanding of supply performance and to generate a method by which optimization through effective trade-offs can be obtained. In these terms, the COMPELS model covers the full range of responsibility of the USAMC.

216. General Mode of Operation

a. The model begins with a balance sheet presentation of status of a given item of supply at a given point in time. For instance, secondary items will be presented on DA

Form 1794 (Supply Control Study). Transactions, such as issues, losses, demands, status changes, etc., are brought into the program from paper tape or cards, necessary adjustments are made, and the balance sheet is changed accordingly. For principal items, additional parameters are added by giving consideration to the materiel annex of the 5-year force structure and to the PEMA budget. Thus, the model will be the balance sheet and transaction listing showing flows in specific parts of the logistics systems.

b. Other models which do not affect supply performance directly are being developed as ancillary or side routines. As an example, models are planned for the maintenance and rebuild program, the specific accounting functions within the system, the research and de-

velopment process, and the disposal function of the supply cycle. These will be developed in some detail, in order that suboptimization as well as total optimization are possible.

217. Description of the COMPELS Model

The COMPELS model is a collection of individual models representing the functions of the supply system, beginning with research and development and continuing through requirements determination, storage, distribution, procurement, use recovery, repair or overhaul, reissue, phasing out, and final disposal of an item. Figure 44 is a general diagram of the models which together comprise COMPELS. Although the term "model" is used in each block of this figure, there will, in reality, be more than one model to a block.

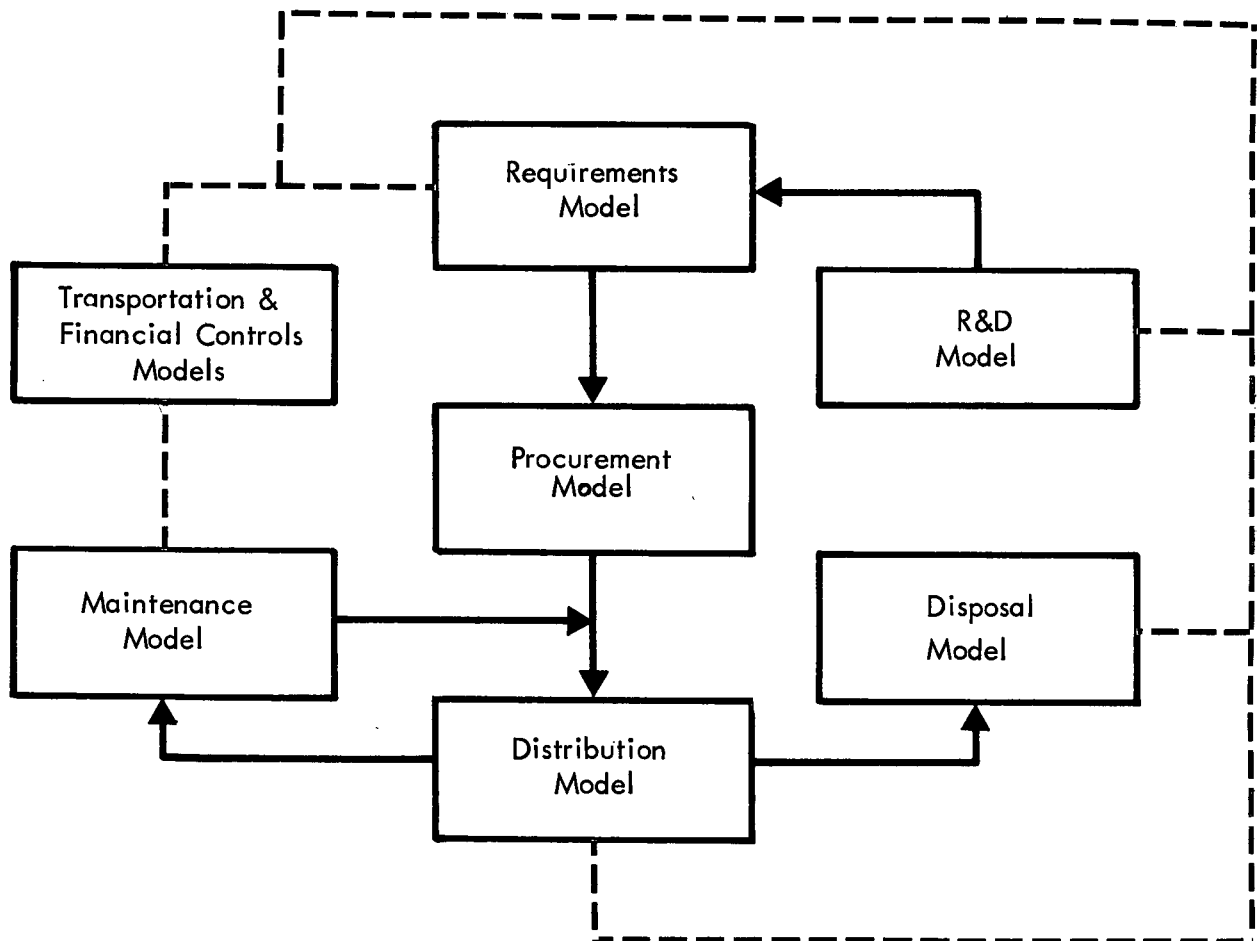


Figure 44. Basic configuration of COMPELS model.

As an example, the requirements model will be subdivided into a principal item model and a secondary item model. The secondary item model will be further subdivided into an HDV model, an MDV model, and an LDV model.

218. Secondary Item Model

The secondary item model begins with the complete Supply Control Study, DA Form 1794. In addition, a complete distribution table and stock status report are presented to include due-in from procurement by time schedule and due-in from repair by time schedule. Transactions are brought in through cards or paper tape. A specialized segment of this model updates the DA Form 1794 and distribution allocation tables and writes the new forms to magnetic tape.

a. DA Form 1794. Under present planning, DA Form 1794 will be completed in every detail for HDV items. Much of the data that would ordinarily be found in the commodity manager's file or in the master record will also be placed in the heading of this form for each item. Thus, the heading will include not only information specified by regulations but also necessary information for the model, including but not limited to the following: smoothing factors; mean absolute deviations and errors for the last two quarters; complete essentiality criteria; and a listing of all principal items the secondary item supports or maintains. There will also be space at the heading to list the TOE and TA allowances of this item for various units, so that the model can be expanded to an all-purpose or all-encompassing model of a total system.

b. The Distribution Table. The stock on hand by condition code at each possible location will be given. The due-in from repair and from procurement at each location will be portrayed by time schedule. The forecasted demand over the operating level period will also be presented, and the stock over or short of the estimated operating level requirements will be depicted at the foot of the distribution table.

c. The Demand History and Returns Data. These tables will give a 24-month history of the returns of serviceable and unserviceable property and the demands for the last 24 months

at each storage location. The model subroutine will update these tables to provide data for updating DA Form 1794 and for support of other parts of COMPELS.

d. Handling and Recording Data. A computer subroutine updates DA Form 1794 and distribution and demand tables by entering and calculating the effects of transactions which have occurred since the last review and listing those supply control actions necessary to bring assets in line with requirements.

219. The Principal Item Model

In order to depict the entire USAMC logistics system, the COMPELS model necessarily contains a principal items model in addition to one for secondary items. A complete description of the principal items model is beyond the scope of this manual. In brief, it will trace authorities and funds beyond DA to the DOD Five-Year Force Structure and Financial Plan and the Federal budget.

220. The Distribution Model

a. The distribution model can be considered in three segments. First, the location, shipment, paper work, requisition flow, and requisition fill; second, a transportation matrix; and third, a pipeline model.

b. The requisition flow model affects and is affected by the distribution table described in paragraph 218, and it will be used to determine the location, amounts, and conditions of stocks on hand and the availability of stocks to fill pipeline demands.

c. The transportation matrix will not only allow for carload, less-than-carload, truckload, and less-than-truckload, but it will also consider premium transportation, mail, and special handling.

d. The primary objective of the pipeline model is to provide a simulation of materiel flow for principal items, and secondary items. To analyze the multi-echelon effect of requirements for these items, demands are first generated for the using or consumer units. These demands can be fixed, by using paper tape; average, by various smoothing routines; and random, by using a stored random number

table or by generating pseudo-random numbers. The random demand distributions are simulated using Monte Carlo techniques for normal, binomial, and truncated normal. Other frequently used demand distributions, such as the Poisson, negative binomial, and exponential (ch 16), can be incorporated into the demand generation program when required. In addition, the actual demand data bank will be used as it is developed.

- (1) The demands of the using units are registered against the next higher echelon or level, referred to as the DSU's (Direct Support Units). Requirements demands are calculated for these DSU's and registered against the next higher level. This process of filling the demands at an echelon, calculating total requirements for the immediate conditions, and ordering from the next higher echelon(s) is repeated for as many as six additional echelons (DSU, GSU, ADV, BASE, COMMZ, THEATER, and CONUS) in an oversea theater. Finally, a single demand representing the total oversea demand is placed on CONUS. During the process, certain parts or even all of any given level or echelon can be eliminated. When any part of the system is eliminated, the next higher echelon is used to furnish the necessary data to continue processing. By eliminating various echelons, different configurations of the pipeline can be analyzed.
- (2) Requirements for each echelon of supply are calculated by using moving averages of recent demands. In the lower echelons, the averages cover smaller periods of time (3 to 6 months), whereas in the higher echelons the periods of time range from 12 to 24 months. Double exponential smoothing for demand forecasts has been programed and will be used for later analyses.
- (3) The on hand and on order authorized stock levels are computed by multiplying the operating level time, the safety level time, and the order ship time

by the average demand. The sum of these three products constitutes the total authorized level for a stocking point.

- (4) The smoothing of demands and the inserting of nonrecurring demands are only two of many alternate routines that can be used to create new and more sophisticated simulations.
- (5) The model is designed to permit simulation of different conditions by changing constraints. This model allows simulation of the distribution system including specialized distribution systems, such as one for POL or one for air items.

221. The Procurement Model

So far as materiel flow is concerned, it makes no difference whether an item is procured by formal advertising or by negotiation, whether set asides for small business and distressed labor areas are a part of the procurement process, or whether the item is procured centrally or locally. Therefore, the procurement model will be represented by simulated time with or without variances, depending upon the desires of the operator.

222. The Overhaul Model

The overhaul model is, of course, tied into DA Form 1794 of the secondary item model. This again is a system that requires a complete analysis which, in itself, contributes little to the materiel flow and the requirements-distribution pipeline. This process must be studied completely to determine not only the effects of changes in maintenance methods and scheduling procedures on the on-time-fill criteria, but also to determine the timing of demands for repair parts. Accordingly, parts of this model will supplement the pipeline model or generate demands on the pipeline model described in paragraph 220.

223. The Disposal Model

As military materiel becomes more complex and even more specialized, disposal problems upon obsolescence become more acute. Accordingly, this model is included in order that the generation of excesses may be simulated and

methods by which excess may be held to a minimum can be determined. Thus, this model, under current planning, is included not to study the marketing capabilities of the disposal centers but to provide a means for improving departmental screening and to analyze the processes leading to the generation and declaration of excess materiel.

224. Data and Sources

Data will be collected from three principal sources — the Major Item Data Agency (MIDA); the Logistics Data Center (LDC); and the individual NICP's. In addition, other data will be generated by specialized models to complete the information necessary for tests over extended periods of time. The identification of specific data and its format will, of necessity, follow the selection of items to be included in the model and the development of methods of data transfer to USAMC. Therefore, significant time has been and will continue to be devoted to the selection, codification, and classification of data and to the problem of maintaining the resulting data bank. It is not planned that the data bank will have extensive value approximating or competing with those of MIDA, LDC, or DCSLOG Data Processing Center. Instead, emphasis will be placed on building a data system for COMPELS in such a way that items may be added, substituted, or deleted quickly and data flow will place minimum requirements on the sources of the data. Preliminary planning has been devoted to the development of Monte Carlo techniques, random number generators, and variance analysis procedures for data generation. It is currently believed that many tests and studies can be conducted with almost any data. This conviction is tempered, however, by the self-imposed restriction that results obtained through tests and simulations using generated data will in every case be verified by the use of actual data, if the actual data are available or can be obtained. The collection of data is thus receiving close attention during this early period of development of COMPELS. On the other hand, the development of the model is progressing independently of data collection. Simulations on the model over the next few months will be verified at a

later time using actual data from sources enumerated above.

225. Availability

The computer center at USALMC, Fort Lee, Va, through the use of the COMPELS model, provides a focal point for logistics simulations. This model will be available for use by all USAMC Commands.

226. Objectives

The main objectives of the model development are as follow:

- a. To provide a method by which current logistics systems may be effectively studied in detail.
- b. To identify weakness in existing procedures and systems and to recommend improvements.
- c. To test scientifically those concepts and procedures recommended for improvements, without resorting to expensive field trial and error tests.
- d. To provide a means for accelerating the scientific evaluation of proposed procedural and conceptual changes to the logistics system.

227. Applications

Some specific, planned applications of the model indicate the expected comprehensiveness of the model.

- a. Measure the effect, at the NICP level, of quarterly versus annual limitations on procurement funds.
- b. Measure system effectiveness of one safety level concept as opposed to another.
- c. Measure the total costs in manpower, storage facilities, and transportation of selected rebuild concepts.
- d. Evaluate and compare procedures used by different NICP's or between proposed and operational techniques.
 - (1) Stockage Policies
 - (2) Stock Rotation Procedures
 - (3) Dispersion Rules
 - (4) Depot Site Selections

- (5) Local Versus Centralized Procurement
- (6) Demand Forecasting Methods.

228. Summary

The basic main program of the COMPELS system is currently available for use. It will

be extended by adding subroutines in all areas of logistics management. It is likely, however, that continual updating, revising, and innovating efforts will be required to maintain the model current with the rapidly developing science of supply management.

CHAPTER 15

STATISTICAL DISTRIBUTIONS AND CURVE FITTING

Section I. GENERAL

229. Introduction

a. Many of the recent advances in inventory techniques are based on statistical concepts. The total demand placed on a supply facility, the average order size, and the number of different line items requisitioned over a fixed period of time do not remain constant from period to period. They incorporate instead features of random variability. For this reason, modern inventory systems have turned to the techniques of statistical analysis and mathematical model building as a means of handling and analyzing these random processes.

b. The inventory demand patterns of secondary items are often characterized by low demand rates that are subject to considerable variation or fluctuation from one time period to the next. Further, although any demand size is possible, certain values of periodic demands are more likely to occur than others. A statistical method of stating the likelihood of a certain number of demands is to express the demand pattern in terms of a frequency distribution or a probability statement.

230. Probability Distributions

a. Consider the following hypothetical example of demands for 25 months for an individual stocked item:

Monthly Demands				
0	1	4	0	1
1	3	1	0	1
2	1	0	3	2
0	2	1	0	0
2	0	1	1	2

b. An initial examination of these data would probably emphasize the extreme values of the observed demands. For example, the largest quantity demanded in the preceding list of 25 demands was 4, while the smallest value of a demand was 0. Although this information is of some use, it is more helpful to summarize these

data in terms of the frequency with which each demand size occurred (the observed demand sizes were 0, 1, 2, 3, and 4). The occurrence frequency for each demand value has been listed in column 2, table 18. The derivation and use of the information listed in columns 3 and 4 will be discussed in the following paragraphs.

c. Another way of looking at the demand pattern is to divide each of the numbers in column 2 by the total number of demands recorded, in this case 25. The result of such a computation is called a *relative frequency*. The relative frequencies for the sample under consideration are given in column 3, table 18. A relative frequency is also a *probability*; that is, it corresponds to the probability of observing a demand for X units (where X is a value of a monthly demand, i.e., 1, 2, 3, or 4). In this case, the letter X stands for a random variable; that is, a number that can take on specific values with a fixed probability. $P(X=0)=.32$ represents the probability that a demand for zero units will be observed. $P(X=1)=.36$ represents the probability that a demand for one unit will be observed, etc., up to $P(X=4)=.04$. Another way of stating that $P(X=0)=.32$ is that 32 times out of 100 the demand will be for zero units.

d. When all of the probabilities corresponding to the possible outcomes of a random variable are listed, as in column 3, table 18, the result is referred to as a *probability distribution*. Distributions of this type are often represented graphically in terms of a histogram or a continuous curve as shown in figure 45.

e. Most actual demand data, when graphed, can be shown to approximate some standard mathematical pattern or distribution function. The construction of histograms is, therefore, a useful technique when the problem is to identify

Table 18. Summary of 25 Observed Monthly Demands for a Given Stocked Item

Summary of 25 Observed Monthly Demands for a Given Stocked Item

1	2	3	4
Size of Demand (X_o)	Frequency (f)	Relative Frequency (f/n)	Cumulative Probability $P(X \leq X_o)$
0	8	.32	.32
1	9	.36	.68
2	5	.20	.88
3	2	.08	.96
4	1	.04	1.00
	$n = 25$	1.00	

the type of underlying distribution function that generated the data.

231. Cumulative Distributions

a. Interest is often focused on certain groupings of demand quantities such as the number of demands greater than a specified number (e.g., $X > 1$), or the number of demands less than a specified number (e.g., $X < 4$). In this case, it is useful to express groups of this type in terms of a single number (i.e., the probability of this group being observed).

b. For example, using the hypothetical demand data, consider the probability that the number of demands observed is less than or equal to 2 ($X \leq 2$). The desired probability can easily be obtained by adding together appropriate probabilities given in column 3, table 18, as follows:

$$P(X \leq 2) = P(X = 0) + P(X = 1) + P(X = 2)$$

$$P(X \leq 2) = .32 + .36 + .20$$

$$P(X \leq 2) = .88$$

An expression of this type is referred to as a *cumulative probability*. The numerical values of the cumulative probabilities of the original 25 observations are presented in column 4, table 18. These probabilities are graphically represented in figure 46 as a step function.

c. Sometimes it is convenient to replace the histogram shown in figure 45 or the step function shown in figure 46, by a continuous curve. This has been indicated by the dotted lines on the appropriate graph. Continuous curves are particularly helpful when the number of demands observed for a given item tends to be large.

232. Theoretical Distributions

a. Although it is possible to describe all data by studying demand patterns or distributions generated by a great deal of actual data, this procedure is time-consuming and inefficient. A more convenient technique is to characterize the observed demand patterns by theoretical distributions. These distributions will have approximately the same shape as those that describe the actual data, but desired probabilities can be more easily computed by using the appropriate algebraic relationship.

b. Usually, theoretical distributions can be found that "fit" any demand pattern, and sometimes more than one curve will provide sufficiently accurate estimates of the actual pattern. The problems of selecting the best fitting distribution are considered in paragraphs 247 through 253. In general, when the number of demands observed for a given line item tends to be small,

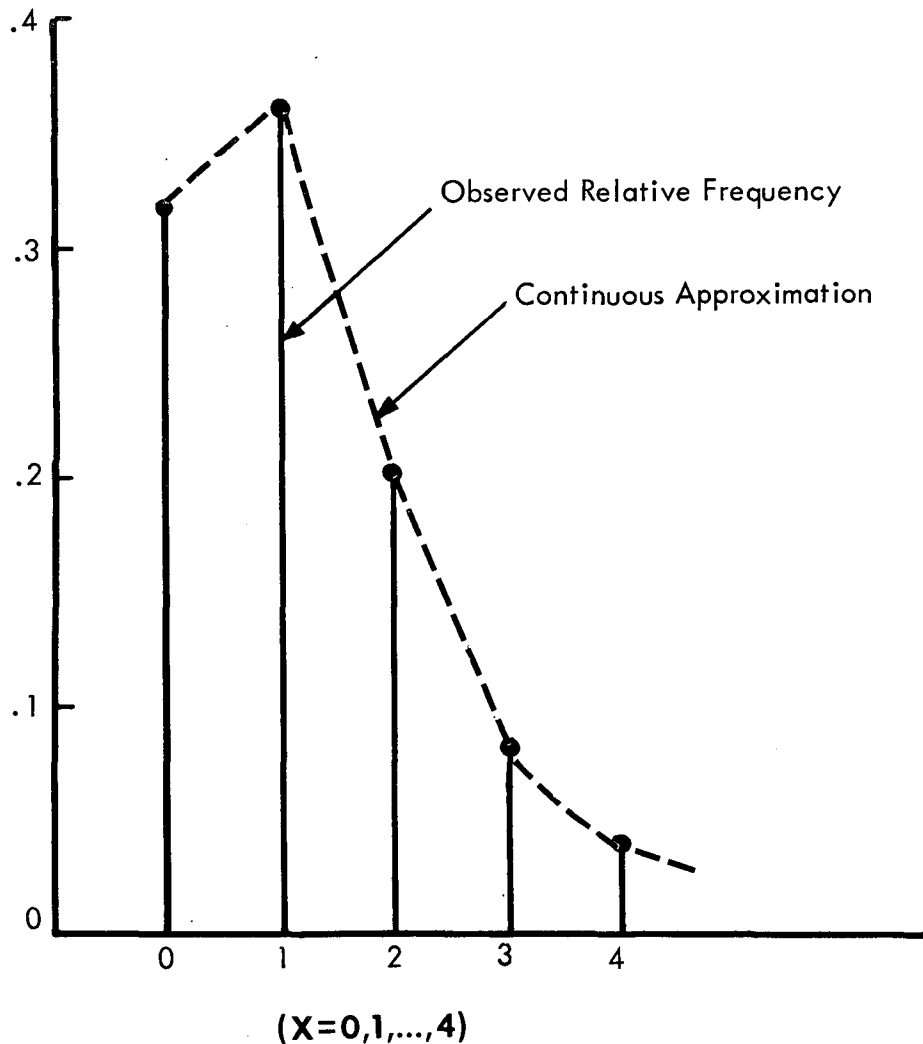


Figure 45. Histogram showing the relative frequency or probability of X demands.

either the Poisson distribution (fig. 47) or the negative binomial distribution (fig. 48) will be applicable. If the observed number of demand items tends to be large, the normal distribution (fig. 49) or log normal distribution (fig. 50) may provide a better fit. The referenced figures illustrate the shapes of these distributions for selected values of their descriptive parameters.

c. Since the size of the demands in the example of 25 observations was small, the Poisson distribution may be appropriate for these data. An actual test of the fit of the Poisson distribution to the hypothetical data is presented in paragraphs 247 through 253.

233. Parameters of the Distribution

a. Before the process of fitting a theoretical curve to demand data can be initiated, it will be necessary to compute certain quantities called *parameters*. A parameter is a number that causes the distribution to change its shape or location as its size or magnitude changes.

b. For example, suppose μ_1 (Greek letter, mu) represents the average demand, or "mean," for a given line item, and μ_2 represents the average demand for a second line item. (The calculation of means is discussed in the next section.) If the two line items under consideration tend to have demand patterns that vary about this mean in a similar fashion, the difference between the two

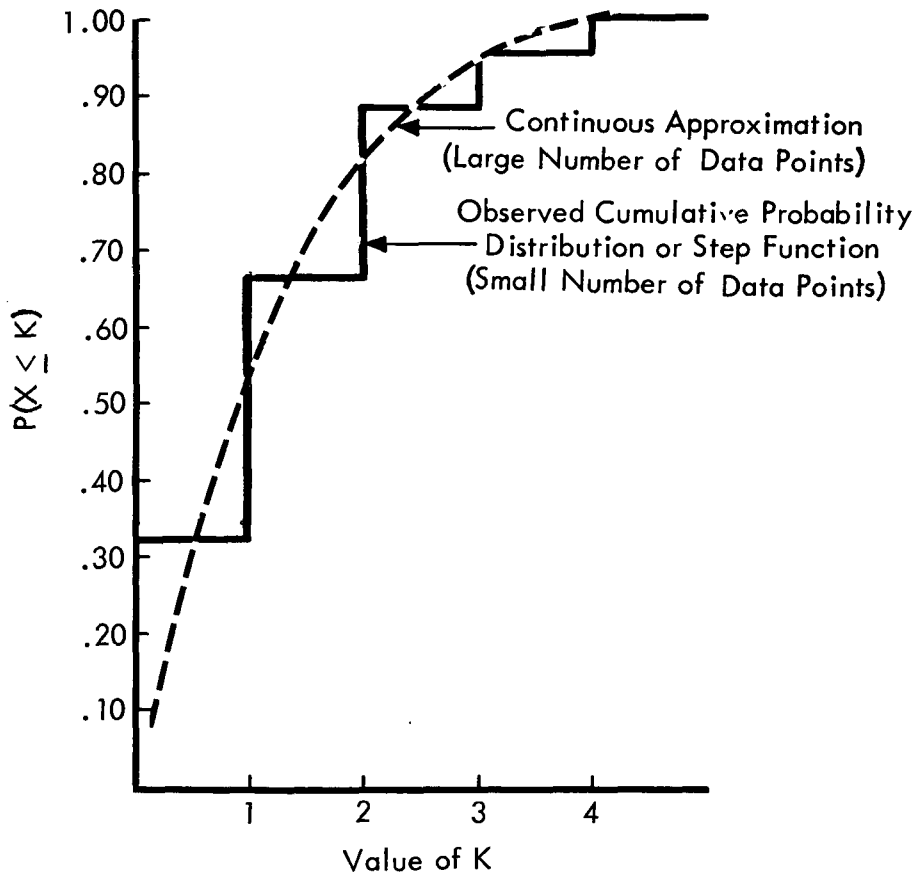


Figure 46. Cumulative probability ($P(X \leq K)$) for the original set of 25 monthly demands.

distributions will be reflected in terms of a difference in location for the two demand distributions as illustrated in figure 51. Thus, μ is a parameter of this distribution, and changes in its numerical value will alter the location of the distribution.

c. Further, let us suppose that the two line items previously discussed have the same average demand, μ , but that line 2 tends to have a more variable demand pattern. The center of these distributions would then coincide but the shapes of their distribution curves would be different. Figure 52 illustrates that an increase in the variability of line item 2 is reflected in a demand pattern that is more spread out. This can be interpreted as representing a demand pattern that includes a greater range of values relative to the size of the mean. A statistic called the "variance" is often used to measure the scatter

of values about a mean. The symbol for variance is σ^2 , sigma squared. (The calculation of variances is discussed in the next section.)

234. Need for Analysis of Distributions

a. Studies of the demand characteristics and variable costs of secondary items have led to the development of a number of mathematical models (e.g., M.I.T. and Harbridge House) that can be used to improve the supply management of these items. These models base certain calculations, principally that of the safety level, on an assumed demand distribution.

b. The problem of knowing which management inventory model to apply may in some cases reduce to a process of choosing the model where the assumed distribution function best fits the catalog items under consideration.

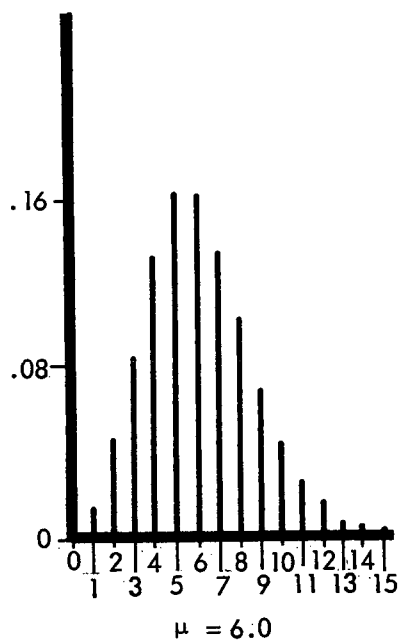
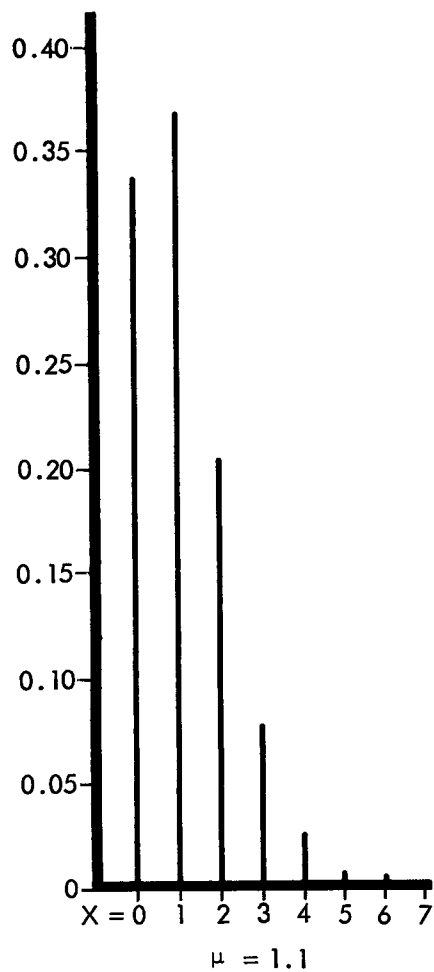


Figure 47. The Poisson distribution for 1.1 and 6.0.

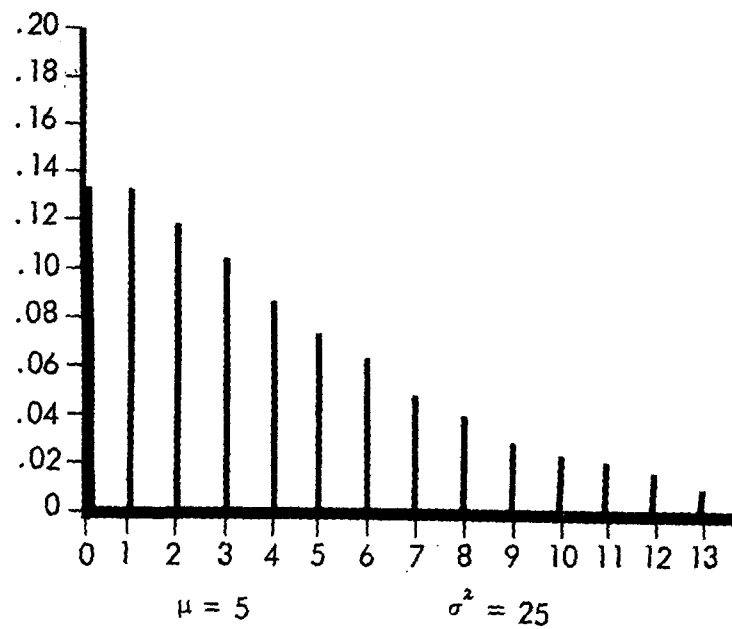
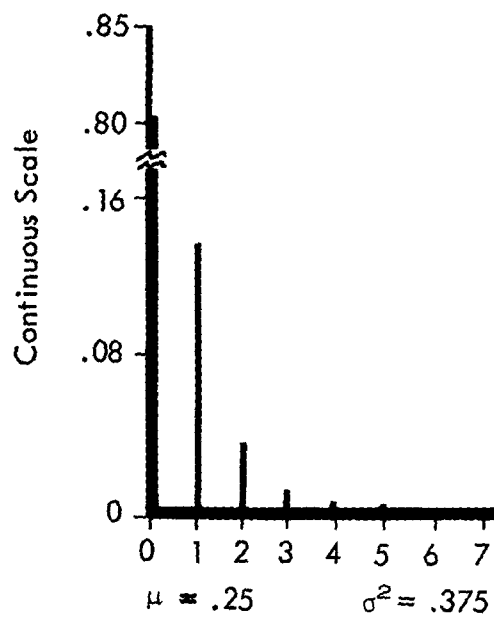


Figure 48. The negative binomial distribution.

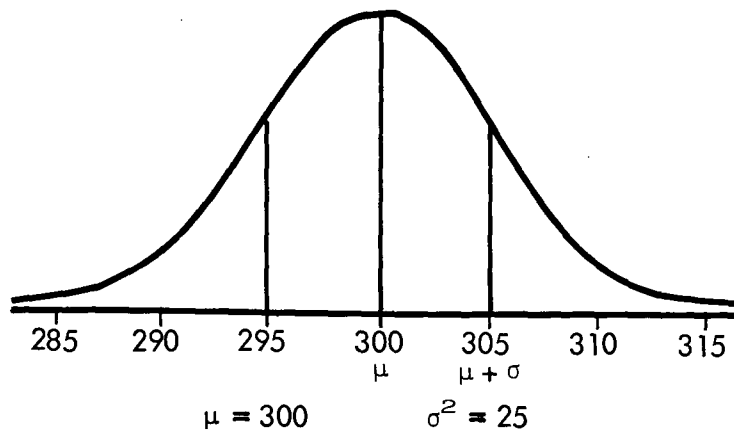


Figure 49. The normal distribution.

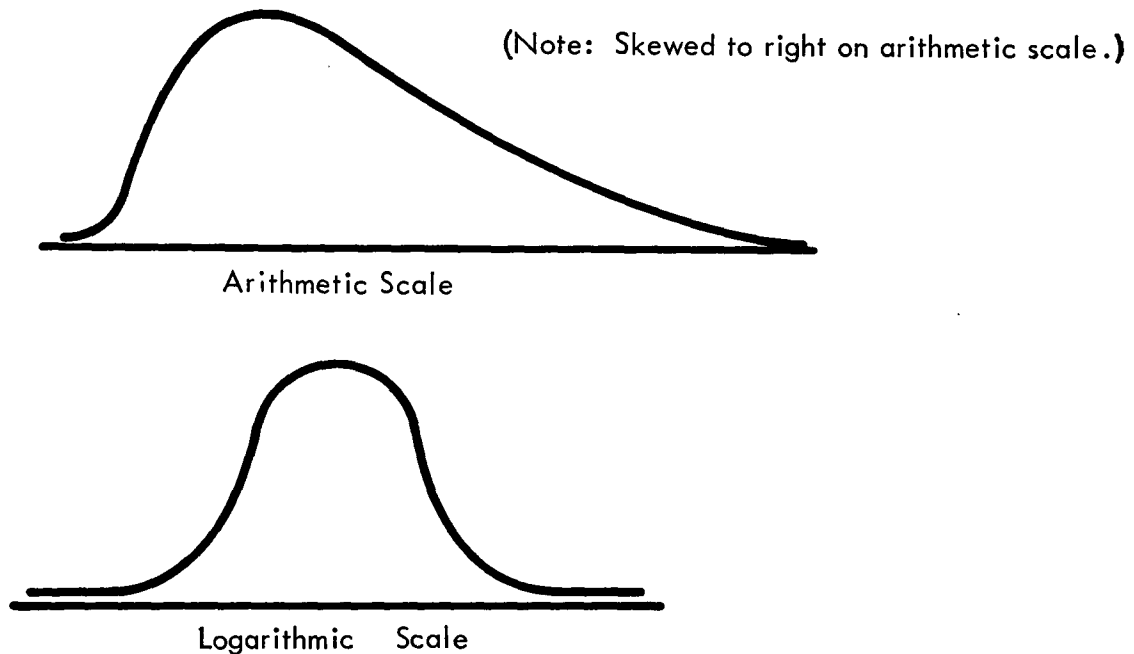


Figure 50. Log normal distribution—or large demand distribution.

c. The M.I.T. model was developed from an analysis of demand data for a small but representative sample of items. After an analysis of selected data, a modified Poisson distribution was functionally related to order size, and demands were treated as being normally distributed over the lead time. On the other hand, Harbridge House, using demand data for certain electronic components, found the gamma distribution more appropriate.

d. In the following sections, some of the more common theoretical distributions will be intro-

duced. Their essential parameters are identified and special applications discussed. As mentioned earlier, paragraphs 247 through 253 will treat two arithmetic techniques for testing whether or not a given distribution applies to selected data. While the examples in this section will be solved manually, it should be noted that library programs that will permit the calculations to be performed on ADP equipment are available for the NICP's computers. However, while computer programs for testing degree of fit are available, it should be recognized that a great

deal of manual preparatory work is nonetheless required to normalize and edit the data, to match reversal transactions, to remove errors and outliers, and to perform other necessarily manual tasks.

e. It is not recommended that NICP's routinely

check demand distributions either manually or on their computer. It is recommended, however, that such analyses be made before a new inventory control model is implemented and selected for HDV items that are habitually in short or long supply conditions.

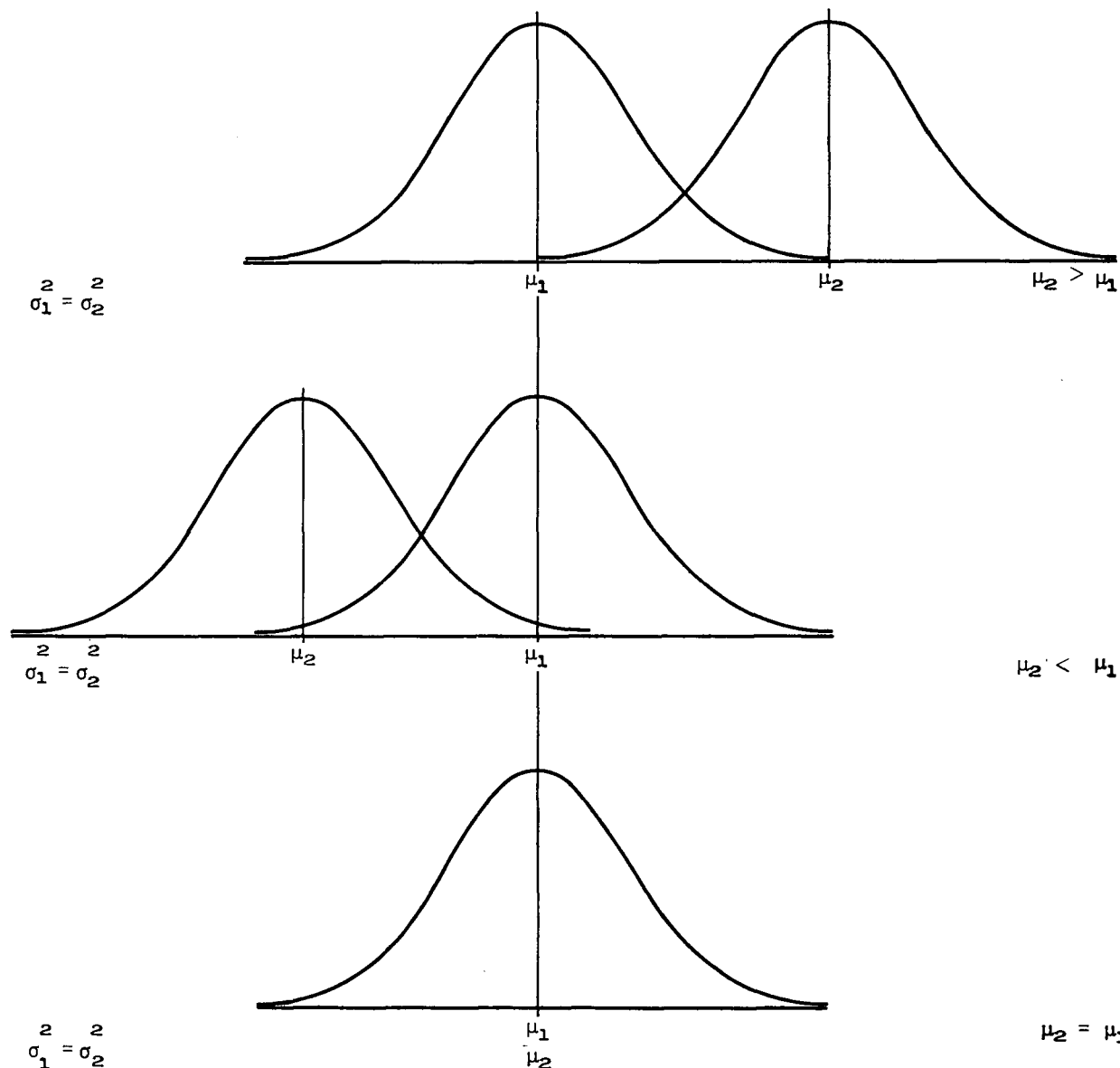


Figure 51. The distribution of total demands by line item illustrating the effect of changes in the mean values of a normal variate.

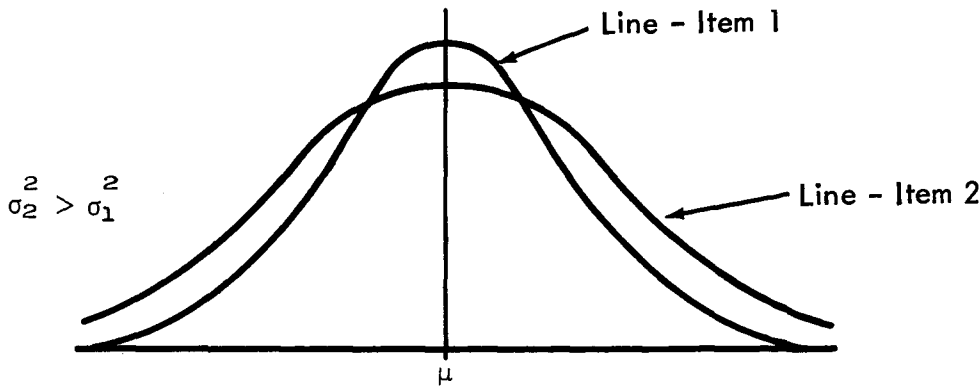


Figure 52. The distribution of demands for two line items with the same average demand but different ranges in size of requests.

Section II. MEAN AND VARIANCE

235. General

a. In the previous section, it was noted that the shape of a distribution is affected by the numerical value of certain quantities called parameters. In this section, attention will be focused on two special parameters that have a variety of uses in demand analysis and forecasting. These two quantities are the mean and the variance.

b. These parameters sometimes enter into the mathematical expression for the demand distribution, as is the case for the Poisson and normal distributions. On the other hand, the mean and variance always represent useful descriptors of demand patterns, even when not part of the distribution function.

236. Mean

a. The average demand of an item is referred to as the *mean* demand and is often represented by the Greek letter mu, μ . When an estimate of a mean is made from a sample of data, it is shown as $\hat{\mu}$, read mu "hat". The mean is a measure of central tendency and its numerical value represents the location about which the demand pattern tends to fall.

b. Consider n observations $X_1 \cdot \cdot \cdot X_n$. How can the average demand of these values be determined? The computation of the mean or average demand is straightforward. One merely sums all the observations and divides by the number of observations used in obtaining the total. Symbol-

ically, this can be written $\hat{\mu} = \sum_{i=1}^n X_i / n$, where Σ (capital sigma) indicates the required operation of adding the n numbers together.

c. To illustrate this procedure, consider the data given in the first section. The average demand becomes

$$\hat{\mu} = \frac{0 + 1 + 2 + 0 \cdot \cdot \cdot = 2}{25}$$

$$\hat{\mu} = 29/25$$

$\hat{\mu} = 1.16$ units requested on the average.

d. If the underlying demand pattern were Poisson, the theoretical distribution could be "fitted" using only the above estimate of the mean, $\hat{\mu}$, and the basic mathematical expression for the Poisson, as will be illustrated later.

237. The Variance, or the Measure of Spread

a. A second parameter of importance in the analysis of demand data is the sum of squares of the deviations about the mean. This quantity is called the *variance* when it is divided by the appropriate denominator ($n-1$). Symbolically, the variance can be computed by

$$\sigma^2 = \frac{\sum_{i=1}^n (X_i - \hat{\mu})^2}{n-1}$$

where $(X_i - \hat{\mu})^2$ is the squared deviation of the i^{th} demand record about the estimated mean, $\hat{\mu}$. Note that the variance is generally represented by the symbol σ^2 , read sigma squared. The

Table 19. Computation of Variance for 25 Observations or Demand Records

Computation of Variance for 25 Observations or Demand Records

Observed Demand (X_i)	$X_i - \hat{\mu}$	$(X_i - \hat{\mu})^2$
0	-1.16	1.3456
1	-0.16	0.0256
2	0.84	0.7396
0	-1.16	1.3456
2	0.84	0.7396
1	-0.16	0.0256
3	1.84	3.3856
1	-0.16	0.0256
2	0.84	0.7396
0	-1.16	1.3456
4	2.84	8.0656
1	-0.16	0.0256
0	-1.16	1.3456
1	-0.16	0.0256
1	-0.16	0.0256
0	-1.16	1.3456
0	-1.16	1.3456
3	1.84	3.3856
0	-1.16	1.3456
1	-0.16	0.0256
1	-0.16	0.0256
1	-0.16	0.0256
2	0.84	0.7396
0	-1.16	1.3456
2	0.84	0.7396

$$29.36 = \sum (X_i - \hat{\mu})^2$$

Computation of $\hat{\sigma}^2$

$$\hat{\sigma}^2 = \frac{\sum_{i=1}^n (X_i - \hat{\mu})^2}{n-1}$$

$$= \frac{29.36}{24}$$

$$= 1.2233$$

$n = 25$, the number
of observations

square root of the variance, small sigma (σ), is an important statistic called the standard deviation.

b. Using the 25 observations from the data discussed earlier, the variance $\hat{\sigma}^2$ can be computed as shown in table 19. It is apparent after examining this table that the process of computing $\hat{\sigma}^2$ becomes laborious as n increases.

c. An alternative and simpler computational procedure is presented below, using a modified formula for the variance.

$$\hat{\sigma}^2 = \frac{\sum (X_i)^2 - \frac{(\sum X_i)^2}{n}}{n-1}$$

By using this equation, the computation of $\hat{\sigma}^2$ can be simplified greatly. Note that from table 19 $\sum X_i = 29$. The other expression, $\sum (X_i)^2$, is obtained by squaring each monthly demand and then summing. That is: $(0)^2 + (1)^2 + (2)^2 + (0)^2 + \dots + (2)^2$. For the 25 observed demands in the example $\sum (X_i)^2$ is equal to 63. Therefore,

$$\begin{aligned}\sigma^2 &= \frac{63 - \frac{(29)^2}{25}}{24} \\ &= \frac{(63.00 - 33.64)}{24} \\ &= 1.2233\end{aligned}$$

as previously computed in table 19.

d. Had the original data been from a Poisson distribution, the mean and variance would have

been numerically equal. An examination of the results obtained above shows that the mean μ is equal to 1.16, and the variance σ^2 is equal to 1.22. Although these numbers are not identical, their closeness suggests that the data may well have originated from the Poisson distribution. In paragraphs 247 through 253, the goodness-of-fit test of this hypothesis will be illustrated, and it will be shown that the data do in fact support the hypothesis that the underlying demand pattern was Poisson.

Section III. POISSON DISTRIBUTIONS

238. General

An important distribution in inventory control is the Poisson distribution. This demand pattern may result whenever the total number of demands is counted over a fixed time interval and especially when the demands are small and occurring at random with a constant probability. Examples of things occurring in everyday life that have been shown to fit Poisson distributions are the number of touchdowns scored in a football game, the number of times lightning flashes in a thunderstorm, and the number of flows occurring in a given length of electrical cable.

239. Poisson Distribution

a. It is possible to construct a Poisson distribution knowing only the *mean* or *average* demand, μ . When the distribution has been constructed, it provides estimates of the probability of observing a particular number of demands.

b. The density function for the Poisson distribution has the form

$$P(X_i, \mu) = \frac{\mu^x e^{-\mu}}{x!}$$

where $x!$ means x factorial (e.g., $3! = 3 \times 2 \times 1 = 6$) and μ is the average demand.

c. A convenient method of computing $P(X; \mu)$, the probabilities for the X^{th} demand, is to utilize the following recursion relation:

$$P(X=0; \mu) = e^{-\mu}$$

$$P(X=1; \mu) = p(X=0; \mu) \times \frac{\mu}{1}$$

$$P(X=2; \mu) = p(X=1; \mu) \times \frac{\mu}{2}$$

$$P(X=N; \mu) = p(X=N-1; \mu) \times \frac{\mu}{N}$$

where

$e = 2.71828$, and μ is the average demand.

A recursion expression is an equation that defines one value in terms of the one preceding it.

d. The details of this computational procedure can be illustrated using the 25 demand records presented in paragraphs 229 through 234. Recall that the computed average demand was 1.16 ($\mu = 1.16$). Applying this result to the recursion relation stated above, the probabilities of observing N demands becomes

(1) Demand of zero:

$$\begin{aligned}P(X=0) &= e^{-1.16} \\ &= 0.3135\end{aligned}$$

(2) Demand for 1:

$$\begin{aligned}P(X=1) &= p(X=0) \times \frac{1.16}{1} \\ &= (0.3135)(1.16) = 0.3637\end{aligned}$$

This process is continued until the probability $P(X=N)$ becomes very small. For example, $P(X=7) = 0.0002$ so the process can be terminated.

e. These estimated probabilities can be compared to the relative frequencies computed on a basis of observed demands as a test of "goodness-of-fit."

240. Compound Poisson Distribution

a. Both M.I.T. and the Harbridge House noted during their analyses of items from an Army supply system that the order size was not constant

and that the usual form of the Poisson distribution did not fit the observed demand patterns.

b. The M.I.T. analysis suggested that a compound Poisson distribution may be more suitable in this case as it is not only the total number of demands that is of interest but also the order size. When the chance of observing a particular order size decreases as the number of orders increase, the order size is said to be demonstrating a geometric progression. Such a condition existed in the data analyzed by the M.I.T. group. They therefore selected a distribution that incorporated such a geometric progression on top of a simple Poisson, called a "stuttering Poisson." The stuttering Poisson is a special case of the class of distributions called compound Poissons.

c. One important result of their attempt to describe demand patterns in terms of theoretical distributions was the development of a technique for estimating the variance from demand data when the distribution of order size is not known. The essential determinant when using the M.I.T. model is the variance-to-mean ratio (VMR). The use of VMR is also discussed in chapters 9 and 13

241. Negative Binomial Distribution

a. The Poisson distribution will not apply when, for small demands over a fixed time interval, the mean and variance have been computed and are found to differ considerable in numerical

value. In such a case, the negative binomial distribution may fit the demand pattern better. The negative binomial distribution has been used in several specialized inventory models. More familiar examples of negative binomial distributions include the number of times a coin may be tossed before a head appears and many sickness and accident distributions.

b. The negative binomial distribution can easily be computed using the estimated mean, μ , and variance, σ^2 , and the following recursion relation:

$$P(X=0) = \frac{1}{q^k}$$

where

$$q = \frac{\text{variance}}{\text{mean}}; \quad k = \frac{\text{mean}}{q-1}$$

$$P(X=N) = \frac{k+(N-1)}{N} \frac{q-1}{q} P(N-1).$$

Note that for this recursion relation to apply, the variance must exceed the mean.

c. By substituting the computed values of the mean and variance, q and k can be computed and consequently $P(X=0)$ is determined. The remaining terms are determined sequentially as in the case of Poisson. Again, these estimated probabilities can then be compared to the relative frequencies computed on a basis of observed demands and a test made of "goodness-of-fit."

Section IV. NORMAL DISTRIBUTIONS

242. General

a. One of the most frequently encountered demand patterns is graphically represented as a continuous bell-shaped curve and is called the normal distribution. In the area of forecasting inventory requirements, errors between projected and actual quantities have demonstrated a tendency to form this unique distribution. Further, the "M.I.T." model for NICP inventory control assumes that, when the total quantity of items requested during a stated interval is large, the total demand follows a normal curve. Many things have been found to be normally distributed through statistical analyses. Examples include the heights of men inducted into the Army, the distribution of IQ scores, the weights of minted coins, and the like.

b. The normal probability distribution can be computed when the average demand and the variance of the demands of an item are known or can be estimated. Unlike the Poisson distribution presented in paragraphs 238 through 241, the desired probabilities cannot be computed easily. The numerical value of probabilities is generally obtained by considering the area under the normal curve. Later it will be shown that these probabilities can be obtained by using a table of areas under a "standard" normal curve (i.e., a curve with mean equal to zero and variance equal to one).

243. The Normal Density Function

The density function for the normal distribution is rather complex:

$$f(X) = \frac{1}{\sigma(2\pi)^{1/2}} e^{-(X-\mu)^2/2\sigma^2}$$

where

$$\pi = 3.1416$$

$$e = 2.7183 \text{ (Note } e^{-a} = (2.7183)^{-a}\text{)}$$

μ = the average demand

X = any demand

σ^2 = the variance

σ = the standard deviation

$f(X)$ = the height of the normal curve evaluated at X .

244. Plotting a Normal Curve

a. Once the mean and variance have been specified, the height of the normal curve can be computed for a set of points corresponding to different values of X . The height of this curve at these points can be connected by a curved line, thus generating the normal curve.

b. Consider the following demand situation:

$\mu = 100$ demands (on the average)

$\sigma^2 = 25$

$\sigma = 5$.

c. The problem is to evaluate $f(X)$ for enough points so that a picture of the "theoretical" normal curve can be obtained. Suppose $X = 90, 95, 100, 105, 110$ are selected; when $X = 90$, $f(X)$ becomes

$$\begin{aligned} f(X) &= \frac{1}{5\sqrt{2(3.14)}} (2.7183)^{-\frac{(90-100)^2}{2(25)}} \\ &= (0.07979)(2.7183)^{-2} \\ &= (0.07979)(0.135335) \\ f(X) &= 0.01080. \end{aligned}$$

It should be noted that the $(2.7183)^{-2}$ can be computed or a table of negative exponential values used. When $X = 95$, $f(X)$ becomes

$$\begin{aligned} f(X) &= \frac{1}{5\sqrt{2(3.14)}} (2.7183)^{-\frac{(95-100)^2}{2(25)}} \\ &= (0.07979)(2.7183)^{-1} \\ &= (0.07979)(0.606531) \\ f(X) &= 0.04840 \end{aligned}$$

and so on for the remaining values of X (namely 100, 105, 110). The resulting heights are plotted against the appropriate values of X as in figure 53.

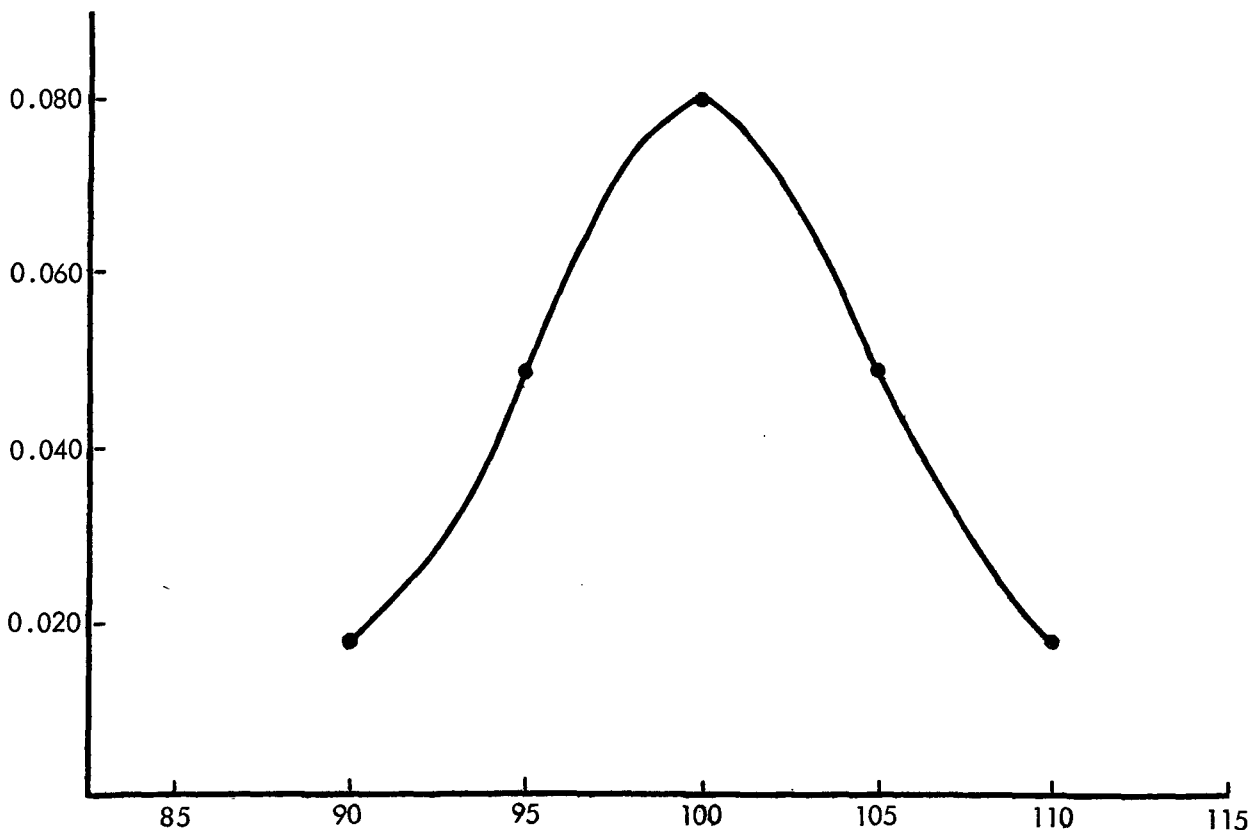


Figure 53. Normal curve constructed from data having mean ($\mu=100$) and variance ($\sigma^2=25$).

Table 20. The Relationship Between the Area Under the Normal Curve and the Proportion Between $\mu \pm k\sigma$

The Relationship Between the Area Under the Normal Curve and the Proportion Between $\mu \pm k\sigma$

<u>k</u>	<u>a = $\mu - k\sigma$</u>	<u>b = $\mu + k\sigma$</u>	<u>P (a \leq x \leq b)</u>
0.5	$\mu - 0.5 \sigma$	$\mu + 0.5 \sigma$	0.3829
1.0	$\mu - 1.0 \sigma$	$\mu + 1.0 \sigma$	0.6827
1.5	$\mu - 1.5 \sigma$	$\mu + 1.5 \sigma$	0.8664
2.0	$\mu - 2.0 \sigma$	$\mu + 2.0 \sigma$	0.9545
2.5	$\mu - 2.5 \sigma$	$\mu + 2.5 \sigma$	0.9876
3.0	$\mu - 3.0 \sigma$	$\mu + 3.0 \sigma$	0.9973

245. Computing Probabilities

a. The area under the normal curve can be interpreted as a probability statement (e.g., the area between plus and minus one standard deviation from the average demand is equivalent to a probability of 0.68). A more detailed breakdown of these probabilities in terms of the standard deviation is given in table 20.

b. Table 20 also shows the relationship between the area under the normal curve and the corresponding probability. The area under a curve lying between the two points $a = \mu - k\sigma$ and $b = \mu + k\sigma$ can be interpreted as—

- (1) The proportion of demands that will have a numerical value between a and b , or
- (2) The probability that a specified demand lies between a and b .

c. The relationship between area under the normal curve and probability is shown graphically in figure 54. The shaded area in the top curve is the probability that a value observed for Z will be equal to or less than b . In the middle curve,

the shaded area represents the probability of a value equal to or less than a . Finally, in the lower curve, the shaded area represents the probability of observing a value that lies between a and b .

d. A relatively easy transformation reduces all normal distributions to a normal distribution with mean 0 and variance 1. Let

$$Z = \frac{X - \mu}{\sigma}$$

where

X = the observed number of demands
 μ = the average demand
 σ = the standard deviation.

This function is very useful, and the Bureau of Standards tables provide a ready source for obtaining the probabilities associated with specified intervals of the standard normal distribution.

246. Log Normal Distribution

The log normal distribution is observed in the distribution of items in inventory relative to annual dollar demands. The use of this function in the selective management of inventories was discussed in chapter 3.

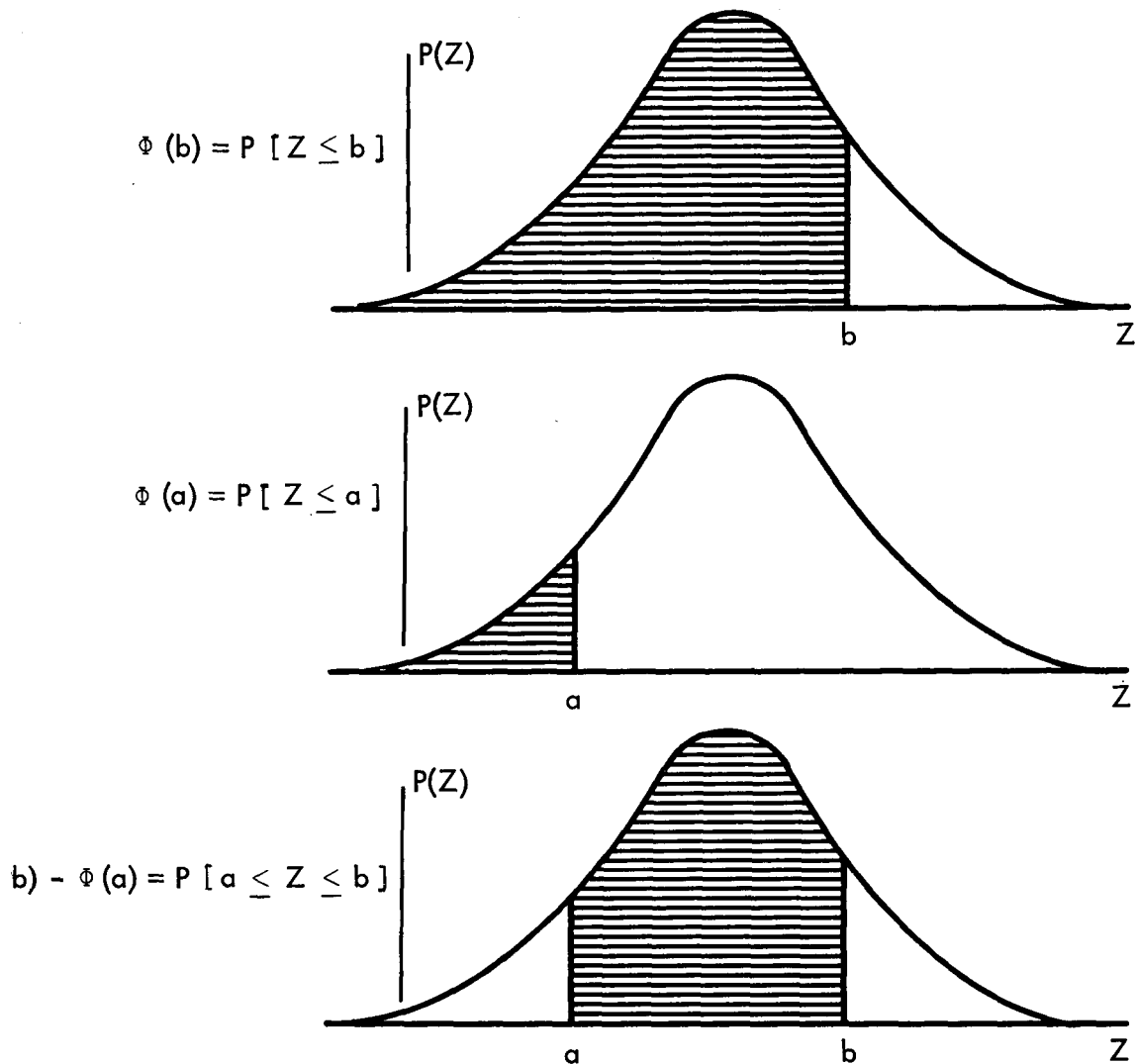


Figure 54. The relationship between area and probability illustrated for a standard normal density with $(a < b)$.

Section V. CURVE FITTING

247. General

This section is addressed to the analysis of statistical distributions and particularly to "goodness-of-fit" tests. The "goodness-of-fit" techniques discussed in paragraphs 250 through 253 are relatively complex and specialized nomenclature is introduced that may only confuse the nonmathematically oriented reader. These paragraphs have been included for that small group of personnel who have a good background in mathematics and statistics, who wish to apply these "goodness-of-fit" tests to demand data, and who might not otherwise have a suitable reference readily available.

248. Introduction

a. In paragraphs 229 through 246 it was noted that data obtained during the inventory control process can be represented in the form of a mathematical function. The exact form of the density function usually is not known; but through an analysis of many records, or from a consideration of prior information, it is often possible to choose a likely curve and attempt to fit the data to this particular density function. In order to use this technique, the analyst should in each case test the assumption that the designated curve is representative of the data.

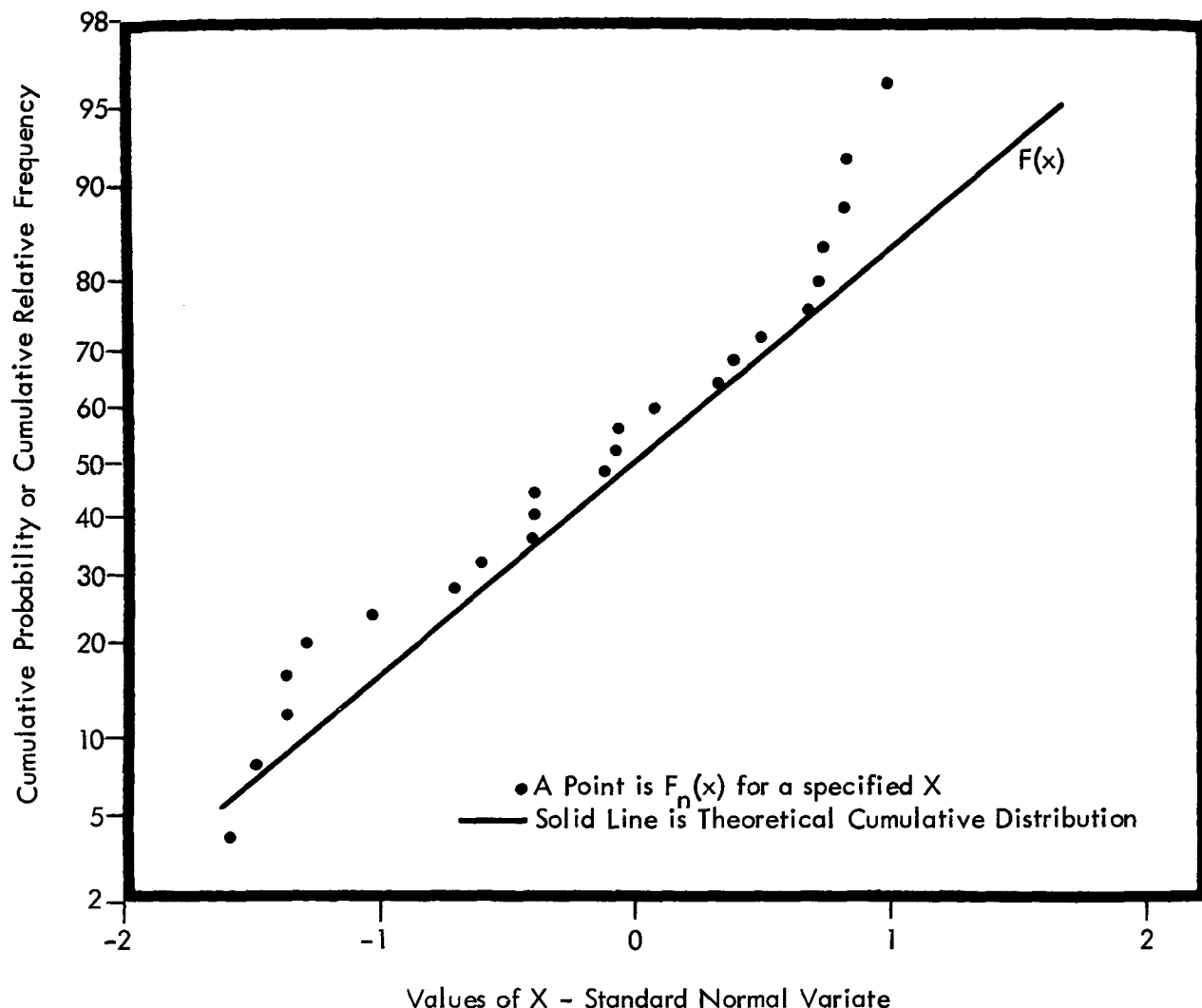


Figure 55. Graphical comparison of 25 observed random normal variates and the theoretical standard normal curve.

b. Where a normal distribution may apply, "normal probability paper" is available for testing underlying normality. In this case, the test reduces to seeing if the cumulative relative frequencies, when plotted against the total demand, graph a straight line. The 25 cumulative relative frequencies summarized in table 23 have been plotted on normal probability paper in figure 55. The "goodness" of this fit with the solid straight line is arithmetically evaluated in table 22. The subject of probability paper was also discussed in chapter 3, where a second type of graph paper called "logarithmic normal" probability paper was used in the analysis of the distribution of annual demands of items carried in inventory.

c. The manual plotting of data points, relative frequencies, or cumulative relative frequencies is one method of attempting to determine an underlying demand distribution. Since manual plotting "visualizes" the data, it is perhaps a valuable first step. However, more precise fitting of curves can be accomplished through arithmetic techniques, and these can be applied directly if the analyst has some reasonable objective or subjective basis for the selection of a particular demand distribution.

d. This section will deal primarily with two nongraphical techniques for testing whether the data will support the hypothesis that a given density function can be used to represent the observations. The first technique is called the

chi-square test of goodness-of-fit, and the second procedure is called the Kolmogorov-Smirnov test. Each of these tests will be treated separately since they apply to slightly different situations.

249. An Approach to Distribution Analyses

a. As stated in paragraphs 229 through 234, it is recommended that NICP's investigate statistical distributions only when planning to implement a new inventory control model or for problem HDV items. The time and expense involved relative to the improved representation of item characteristics would not justify additional analyses.

b. A new or improved inventory control model must be based on certain assumptions as to underlying demand distribution(s). For this reason, it is axiomatic that the research group involved in the models' development include experienced mathematicians and statisticians familiar with classical demand distributions and ways of testing their degree of fit with actual demand patterns. Therefore, if a new model is being developed for an NICP, NICP management need only concern themselves with the technical competence of the development group. On the other hand, if an NICP is planning to install a model developed elsewhere, it is necessary to determine what distribution was assumed in the model and whether the demand distribution of its own stock items fits this distribution with sufficient accuracy.

c. An analysis of an existing model and comparison of the models' statistical distribution with actual NICP data could be performed by any of several groups: NICP personnel, staff of the Army Logistics Management Center, Ft. Lee, Va., the AMC Inventory Research Field Office, Frankford Arsenal, Phila., Pa., or a qualified technical contractor. In all cases, the approach would be about the same.

- (1) Obtain and evaluate technical reports on the proposed model.
- (2) Determine which statistical distribution(s) the model incorporates.
- (3) Collect demand data on a representative sample of the NICP items to which the model would be applied.
- (4) Plot distribution frequencies for a few randomly selected items and calculate their means and variances.

- (5) Test goodness-of-fit with proposed models' assumed distribution.
- (6) Test goodness-of-fit with other classical distributions believed more suitable.
- (7) If best fit is with the models' assumed distribution, proceed with the models' implementation.
- (8) If another distribution provides a better fit, either modify model to incorporate this distribution, abandon plans to implement the new model, or test sensitivity of the model to different distributions using simulation techniques.

d. HDV items should be selected for analysis of demand distributions on an exception basis. Only those items that constitute a problem in terms of being habitually in long or short supply or that are of special interest for reasons of cost or military essentiality should be considered for this special treatment.

e. After appropriate HDV items have been identified, the analysis should proceed as follows:

- (1) Assemble an adequate amount of purified demand data. A minimum of 20 data points (and preferably many more) representing demand over comparable time intervals will be required.
- (2) Calculate and plot relative frequencies and cumulative probabilities.
- (3) By inspection of graphs, select candidate statistical distributions and test goodness-of-fit using appropriate techniques (para 250-253).
- (4) After determining which distribution best fits actual demand data, calculate appropriate theoretical parameters (mean, and variance or standard deviation).
- (5) Modify model and/or supply control study forecasts to incorporate calculated means (AQD) and variances (safety level).
- (6) Construct control charts and plot current data on a monthly or quarterly basis to insure prompt identification of a significant change in demand pattern. Both mean and range charts should be used. Warning lines two standard deviations away from the expected value are recommended. These charts will be similar to the quality control charts often used in industry. (See any basic statistical textbook for more infor-

mation on the construction and use of control charts.)

- (7) When the control charts indicate a marked change in demand pattern, repeat (1) through (6) above.

250. Definitions

Several new terms and expressions must be introduced in this section for the sake of accuracy of nomenclature. Their definitions follow:

a. Null Hypothesis (H_0). The particular density function to be tested. If the observations are discrete, we would have $H_0: p(x) = p_0(x)$, where $P_0(x)$ is a particular discrete density function. If the observations are continuous, we would have $H_0: f(x) = f_0(x)$, where $f_0(x)$ is a particular continuous density function.

b. Alternative Hypothesis (H_a). This means that the data do not correspond to our original choice of a density function.

c. Test statistic (T). A quantity computed from the observations that can be used to test the validity of our assumed density function. For the chi-square test, $T = X^2$ (note that the capital of the Greek letter chi is represented by an X). For the Kolmogorov-Smirnov test, $T = D_n$.

d. Significance Level (α). The probability that we will reject H_0 when in fact it is true. T_α is called the α level critical value.

e. Interval (I). Any range over which a probability can be computed. If X is a discrete random variable, the probability is concentrated at a point. If the random variable is continuous, the data can be grouped into intervals over which the probabilities can be computed.

f. O_i . The number of our observations that lie in the i^{th} interval, or that take on a particular value.

g. E_i . The expected number of observations that lie in the i^{th} interval, or that take on a particular value.

251. Procedures for Determining the Expected Number of Observations

a. Discrete Data.

- (1) The technique will be illustrated by an example. Suppose that the 25 demand records presented in paragraphs 229

through 334 are tested to determine whether they represent a sample from a Poisson distribution with an average demand of 1.16.

This hypothesis can be stated as

H_0 the distribution is Poisson with $\mu = 1.16$

H_a some other distribution is applicable.

The test reduces to a comparison of the observed number of times X demands occur to a set of numbers computed under the assumption the H_0 is true.

- (2) The expected number of demands corresponding to each category ($X=0, 1, 2, \dots$) is obtained in the following manner:
- Compute the numerical values of the probabilities for each demand level by evaluating the recursion relation for the Poisson distribution. With $\mu = 1.16$ these probabilities are given in column 3, table 21.
 - The expected number of demands is obtained by multiplying each probability by the total number of observations (25) as in column 4, table 21.

b. Continuous Data.

- (1) Suppose that prior considerations suggested that the data (another set) were being generated from a normal distribution with zero mean and variance equal to one (i.e., a standard normal). Consider the following 25 observations from such a situation:

-0.705	-1.283	-1.283	-0.600	-0.380
-1.486	-0.385	0.720	0.732	0.685
-0.122	0.820	-1.359	0.839	-0.074
-1.594	-0.399	-0.060	0.077	1.683
0.997	0.498	0.396	-1.360	0.336

These observations can be grouped into any number of intervals (I), and the probability of an observation falling in a specified interval can be determined from a table of standard normal integrals.

- (2) The following two steps are required to evaluate the expected number of observations in a continuous situation:
- Compute the proportion of observations expected in the i^{th} interval, i.e., more specifically, for the example under consideration four intervals are used, namely,

$$\begin{array}{ll} I_1 = -\infty \text{ to } -1.0 & I_3 = 0.0 \text{ to } 1.0 \\ I_2 = -1.0 \text{ to } 0.0 & I_4 = 1.0 \text{ to } \infty \end{array}$$

$$\nu = k - l$$

The probabilities associated with each of these intervals is obtained using a table of standard normal integrals. Thus,

$$\begin{array}{ll} P_1 = 0.1587 & P_3 = 0.3413 \\ P_2 = 0.3413 & P_4 = 0.1587 \end{array}$$

- (b) Compute the expected number in each interval from the relationship nP_i where n is the number of observations in the sample. In this case $n=25$, therefore,

$$\begin{array}{ll} E_1 = 3.97 & E_3 = 8.53 \\ E_2 = 8.53 & E_4 = 3.97 \end{array}$$

252. The Chi-Square Test

a. The procedure for testing the goodness-of-fit involves the computation of X^2 , where:

$$X^2 = \sum_{i=1}^k \frac{(O_i - E_i)^2}{E_i}$$

X^2 is called the chi-square statistic. It is a random variable with a specific density function of its own called the chi-square distribution. To determine if the density function being tested ($p_o(X)$) is a good representation of the observations, we compare the computed value of X^2 with a tabled value $X^2_{\alpha, \nu}$, where α is the significance level and ν is a parameter called the degrees of freedom (tabled values of the chi-square statistic are available in most statistical textbooks). If the test statistic, X^2 , is less than $X^2_{\alpha, \nu}$, we accept the null hypothesis (i.e., we say our fit is adequate). On the other hand, if X^2 exceeds $X^2_{\alpha, \nu}$, we reject the null hypothesis (i.e., the data fail to support the assumption that the specified probability density function describes the data). To look up $X^2_{\alpha, \nu}$, we must first decide on the significance level of the test α and compute ν , the degrees of freedom.

b. ν is equal to

$$\nu = k - l - p$$

where

k = the number of intervals or points used in computing X^2

p = the number of parameters estimated from the data.

If the values of the parameters are known, or if they can be assumed known, then $p=0$ and the degrees of freedom can be written

c. As an example of the application of this test procedure, first consider the original 25 observations presented in paragraphs 229 through 234. The details of the computational procedure are listed in table 21. The computed value of X^2 was 0.42, and the test will be based on a chi-square variate with $(6-1-1)=4$ degrees of freedom since the value of the mean parameter has been estimated from the data. The tabulated value of T_{α} , the test criterion, depends on the choice of α , the significance level. Suppose it is decided to reject H_o when it is true five percent of the time (i.e., $\alpha = .05$). The tabulated value of $T_{.05} = 9.49$. Since X^2 is less than $T_{.05}$, $0.42 < 9.49$, the data support the hypothesis that the observed number of observations could have been generated from the Poisson distribution with $\mu = 1.16$. Although it is impossible to prove completely that an hypothesis is true, failure to reject H_o suggests that the probability function being tested will represent a good approximation of the true probability function.

d. It should be noted that the chi-square test applies to both continuous and discrete data but only when the sample sizes are large. Table 22 illustrates the use of the chi-square test for the continuous case, using the random sample of 25 standard normal variables. If the expected number of observations for any given interval is less than five, the chi-square test usually should not be applied.

e. As a further example, suppose the computer at the NICP was programmed to compare all demand records for this particular stock item against a Poisson distribution with a different average demand (say $\mu=2$). Would the original sample of 25 demand records support the hypothesis that the average demand was 2 units for this item? A recalculation of the value of X^2 for a Poisson distribution with a mean of 2 is shown in table 23 and in this case the computed value of chi-square was found to equal 10.91. When this number is compared to the tabulated value of $T_{.05}$ with 4 degrees of freedom (9.49), it is clear that the data fail to support the hypothesis that $\mu=2$. Failure to accept the null hypothesis can be interpreted two ways—

- (1) The particular sample used in computing X^2 was *not* representative, or

Table 21. Computational Arrangements of Data for Chi-Square Test Using 25 Demand Records

Computation Arrangement of Data for Chi-Square Test Using 25 Demand Records

Number of Demands (i)	Observed Frequency (O _i)	Computed Probabilities (P _i)	Expected Frequency (E _i)	$\frac{(O_i - E_i)^2}{E_i}$
0	8	0.3135	7.84	.0033
1	9	0.3637	9.09	.0009
2	5	0.2109	5.27	.0138
3	2	0.0823	2.06	* 2.83 .0102
4	1	0.0239	0.60	
5	0	0.0055	0.14	
6	0	0.0012	0.03	
	<hr/> 25	<hr/> 1.0010	<hr/> 25.03	<hr/> .0282

$$X^2 = \sum_{i=0}^4 (O_i - E_i)^2 / E_i = .0282$$

Steps:

1. Choose α (say .05).
2. Determine the degrees of freedom (4 - 1 - 1 = 2)
3. Look up $T_{.05}$ in chi-square table using 2 degrees of freedom
 $T_{.05} = 5.991$
4. Compare X^2 (computed) to Table look up .0282 < 5.991
5. Conclusion: data supports the null hypothesis.

* Last four categories combined to give expected value greater than 2.5, the minimum expected frequency to be used in the X^2 determination.

Table 22—Computational Arrangement for Chi-Square—Sample of 25 Observations from Normal Population with Known Mean (0) and Variance (1).

Computational Arrangement of Data for Chi-Square Test -- Sample of 25 Observations from Normal Population with Known Mean (0) and Variance (1)

Interval No. (i)	Interval of X	Observed No. in Interval	Expected No. in Interval	$\frac{(O_i - E_i)^2}{E_i}$
1	$(-1.0 \leq X)$	$O_1 = 6$	$E_1 = 3.97$	1.04
2	$(-1.0 \leq X \leq 0.0)$	$O_2 = 8$	$E_2 = 8.53$.03
3	$(0.0 \leq X \leq 1)$	$O_3 = 10$	$E_3 = 8.53$.25
4	$(X > 1)$	$O_4 = 1$	$E_4 = 3.97$	2.22
		$n = 25$	25.00	3.54

$$T = \sum_{i=1}^4 (O_i - E_i)^2 / E_i = 3.54$$

Steps:

1. Choose α (say .05).
2. Determine the degrees of freedom ($4 - 1 = 3$).
3. Look up $T_{.05}$ in chi-square table using three degrees of freedom. $T_{.05} = 7.81$.
4. Compare X^2 (computed) to table look up $3.54 < 7.81$.
5. Conclusion: data supports the null hypothesis.

(2) The data were, in fact, generated from a population with a different underlying distribution.

f. Whenever a test of a statistical hypothesis is being conducted, there always exists a risk (equal to the significance level of the test) that

the hypothesis being tested will be incorrectly rejected even when it is true.

253. Kolmogorov-Smirnov Test

a. When data have an underlying continuous distribution and when the number of observations

Table 23. Computational Arrangement of Data for Chi-Square Test of Poisson Distribution with $\mu=2$

Computational Arrangement of Data for Chi-Square Test of Poisson Distribution with $\mu = 2$

No. of Demands	Probabilities	E_i Expected Frequency	O_i Observed Frequency	$(O_i - E_i)^2$
				E_i
0	0.1353	3.38	8	6.31
1	0.2707	6.77	9	0.73
2	0.2707	6.77	5	0.64
3	0.1805	4.51	2	1.40
4	0.0902	2.26	1	1.85
5 + above	0.0526	1.31	0	
		25.00	n = 25	10.75

$$T = \sum_{i=0}^5 (O_i - E_i)^2 / E_i = 10.75$$

Steps:

1. Choose α (say .05).
2. Determine the degrees of freedom (5 - 1 - 1 = 3)
3. Look up $T_{.05}$ in chi-square table using 3 degrees of freedom
 $T_{.05} = 7.82$
4. Compare X^2 (computed) to table look up $10.75 > 7.82$
5. Conclusion: data fails to support the hypothesis $\mu = 2$.

is relatively small, the following test procedure, the Kolmogorov-Smirnov, is applicable. It will be assumed that the null hypothesis can be specified completely and that no special alternative is being considered.

b. Let $F(x)$ be the probability that $X \leq x$ is computed from the specified density function:

$$F(x) = \int_{-\infty}^x f(x) dx$$

i.e., the integral (\int) over the range $(-\infty, x)$.

c. $F_n(x)$ is then an estimate of the probability (or cumulative relative frequency) obtained by giving each observation equal weight $1/n$ as follows:

Table 24. Computational Arrangement of Data for Komogorov-Smirnov Test

Computational Arrangement of Data For Kolmogorov-Smirnov Test

Observations In Increasing Order (x)	Cumulative Relative Frequency Observed $F_n(x)$	Theoretical Frequency $F(x)$	Observed Differences $(F_n(x) - F(x))$ d	Absolute Observed Differences $ d $
-1.594	.04	.05	.01	.01
-1.486	.08	.07	.01	.01
-1.360	.12	.09	.03	.03
-1.359	.16	.09	.07	.07
-1.283	.20	.10	.10	.10
-1.030	.24	.15	.09	.09
-0.705	.28	.23	.05	.05
-0.600	.32	.27	.05	.05
-0.399	.36	.34	.02	.02
-0.385	.40	.35	.05	.05
-0.380	.44	.36	.08	.08
-0.122	.48	.45	.03	.03
-0.074	.52	.47	.05	.05
-0.060	.56	.48	.08	.08
0.070	.60	.53	.07	.07
0.336	.64	.63	.01	.01
0.396	.68	.66	.02	.02
0.498	.72	.69	.03	.03
0.685	.76	.75	.01	.01
0.720	.80	.76	.04	.04
0.732	.84	.77	.07	.07
0.820	.88	.79	.09	.09
0.839	.92	.80	.12	[.12]
0.997	.96	.84	.12	[.12]
1.683	1.00	.95	.05	.05

$D_n = |F_n(x) - F(x)| = .12$
 $T_\alpha = .264$ for $\alpha = .05$

$F(x)$ is obtained from a table of standard normal integrals, such as, the Bureau of Standards Tables.

$$F_n(x) = \sum_{X \leq x} \frac{fX}{n}$$

where fX is the number of observations in our sample with the value $X=x$. Note that both $F(x)$ and $F_n(x)$ are expressions for cumulative distributions. $F_n(x)$ is the cumulative relative frequency obtained from the data, while $F(x)$ is its theoretical counterpart.

d. The test of fit is based on a comparison of the observed and expected cumulative distributions. The test statistic is defined to be

$$D_r = \max |F_n(x) - F(x)|$$

where D_n is defined as the absolute value (without regard to positive or negative value) of the maximum difference between the observed and expected cumulative distributions. If D_n exceeds a tabulated value, the null hypothesis is rejected.

e. In table 24, this procedure is illustrated. Note that the maximum deviation observed was .12(D_n) and the critical value $T_{.05}$ is .21. Therefore, the data support the hypothesis that the 25 observations were generated from a standard normal distribution.

CHAPTER 16

REORDER POINTS AND INVENTORY MODELS

Section I. GENERAL

254. Types of Inventory Models

a. As has been mentioned in earlier chapters, the two fundamental inventory questions are when and how much to order. Similarly, there are two basic inventory control models. One of these, the "Q" or quantity model, is based on a fixed order quantity. The other basic model is often referred to as the "P" model and operates on the basis of a fixed order period. As will soon be evident, however, there are many variations of each of these models as well as a model combining both features.

b. Four models discussed frequently in inventory control literature, which have been applied to many commercial situations, can be briefly summarized as follows:

- (1) *Continuous Review Q Model.* This is the classical economic lot size model. The economic order quantity is generally determined by a formula that minimizes the combined variable costs associated with ordering and holding inventory. With continuous review (perpetual inventory records), the EOQ is assumed to be ordered at the instant the stock level falls to a predetermined reorder point.
- (2) *Periodic Review Q Model.* Similar to the simple Q model above, except that inventory status is checked on the basis of a fixed time interval (e.g., weekly, monthly, or quarterly). The EOQ for this model may be determined in the same fashion as when review is continuous. However, the reorder point quantity for a periodic review Q model must contain an allowance for expected demand during the interval between reviews.
- (3) *Simple Replenishment Model.* The simplest fixed order period, varying order

quantity model is referred to as a replenishment model or, sometimes, as a maximum liability model. In this model a maximum quantity to have on hand and on order is determined (e.g., requirements or requisitioning objective), and whenever cyclical reviews are made, an order is placed that will bring assets up to this desired maximum.

- (4) *Optimal Replenishment Model.* In this model the order quantity is generally variable and represents a difference between present and maximum desired assets as is true of the simple model above. Also, in both models review is normally on a cyclical basis. However, this model differs from the simple model in that an order is not necessarily placed every review cycle but, rather only when assets fall below a predetermined level, "S". When optimal replenishment model is operated on the basis of continuous review, the quantity S becomes the reorder point, the maximum level less S is the fixed reorder quantity, and the model operates in much the same way as a simple Q model. This model is often identified in inventory control literature as an (S, s) model, but, since technical authors have not been entirely consistent in their use of the (S, s) nomenclature, it will be called an optimal replenishment model in this field manual.

c. Essentially all inventory models now used in industry or within the military services fall into one of the four above classifications. Model variations arise out of "exception" rules and because of relative emphasis given different factors during the design of a specific model. In the Army, inventory control below the NICP

level is generally on the basis of the simple replenishment model. A requisitioning objective is determined, a periodic review is made of asset condition, and an order is placed that will bring on hand and on order assets up to the RO quantity. The models used at the NICP's more closely resemble the optimal replenishment model. Also, since these NICP models operate on the basis of an essentially continuous review, they contain features of the simple Q model.

255. Factors Determining Model Design

a. The simplest inventory models are based on a consideration of only two opposing costs—the cost to order and the cost to hold. When a third cost, the cost of being out-of-stock, is introduced, complex mathematical expressions are required that are difficult to solve and explain. To illustrate this point, consider these two expressions for total variable cost:

$$(1) TVC_1 = \frac{CY}{Q} + \frac{UHQ}{2}$$

$$(2) TVC_2 = \frac{CY}{Q} + \frac{UHQ}{2} + UH(SL) + \frac{YK}{Q} \int_0^\infty \frac{Q}{f\bar{y}} + LT_{zdx} \left(\frac{Q}{\bar{y}} + LT \right) \bar{y} + SL$$

where

TVC = total variable cost

C = ordering cost/order

Y = average annual demand

\bar{y} = average weekly demand

Q = order quantity

U = unit price

H = holding cost, percent/year

SL = safety level quantity

K = fixed stockout cost/unit

LT = lead time

$\frac{Q}{\bar{y}} + LT_{(z)dx}$ = the $\left(\frac{Q}{\bar{y}} + LT \right)^{th}$ convolution of the basic demand distribution.

The first expression, for TVC_1 , should be recognized as the basic equation used to calculate economic order quantities. In this equation, the first term represents yearly ordering costs and the second term yearly carrying costs to meet average demand. However, the second equation, for TVC_2 , is considerably more complex. The

first two terms are identical to those in the first expression. The third term represents the annual carrying costs of the reserve stock, or safety level. The last term measures the out-of-stock cost and must incorporate a mathematical expression for the demand distribution (ch 15). It is apparent that an inventory model that considers all cost elements (TVC_2) requires the professional capabilities of competent mathematicians and operations research analysts in its development.

b. When quantity discounts are available, the optimum purchase quantity must be determined through an iterative, or trial and error, process. One basic equation (mathematical model) may be used, but it is necessary to solve this expression several times using all legitimate price, quantity, and ordering cost combinations (ch 8).

c. A total logistics system contains several stages or levels. For example, in the Army there are the national NICP, oversea ICP, general support unit, and direct support unit levels, to mention a few. Each of these levels may be treated as a separate entity with individual procurement, issue, and storage problems. In this case, supply control models must be established which optimize performance on an individual basis. Conversely, the entire supply operation can be considered a single system and an overall optimizing model be developed. The latter model, which considers multi-level interactions, would be greatly more complex than the single location-model in terms of both design and operation (ch 17) but would be expected to provide answers that are optimum in a systems context.

d. Inventory models can be refined further when consideration of queuing or waiting line, effects are appropriate. An operations research technique called queuing theory can be used to solve problems involving a finite number of "service stations" and a probabilistic arrival of customers for "service." Inventory models for repairable items must often make use of queuing theory.

e. For the above reasons, the design of an inventory model can be very simple or very complex depending upon how large a system is selected, what cost elements are significant, and how many operating choices exist (e.g., replace, rebuild, or repair). Ultimately, however,

the key inventory management questions still reduce to when and how much to order.

256. Model Parameters

a. In paragraphs 257 through 260, the characteristics of a hypothetical stocked item will be outlined and some representative demand data will be generated. Then, in paragraphs 261 and 262, these data will be used to illustrate the development and operation of the simple and optimal replenishment models discussed above in paragraph 254. Each of these models will be described by two principal parameters—the order quantity and the reorder point.

b. The order quantity may be fixed or variable. When it is fixed it should be an EOQ (ch 8). When it is variable it should still approximate an economic order quantity on the average. This is achieved in a fixed review period model by selecting the time interval between orders to correspond roughly (in terms of average expected demand) to an economic order quantity.

c. The reorder point quantity is normally comprised of one or more of the common inventory stratifications illustrated in figure 56. In the simplest case of a constant demand rate with continuous review, the reorder point quantity may represent only demand over procurement lead time (A, fig. 56). If ordering costs are significant and an EOQ has been determined that is greater than the PROLT requirement (PROLTR), then the reorder point will still be established at the PROLTR, but stock will not continuously be on order (contrast B with A, fig. 56). If, on the other hand, demand is variable, a safety level stratification should be incorporated in the reorder point as has been done in C, fig. 56. Finally, if inventory status is checked at periodic time intervals instead of continuously, an allowance for the review cycle should also be included in the reorder point (D fig. 56).

d. The pertinent characteristics of reorder points and order quantities will be illustrated further with the examples in paragraphs 261 and 262 and then summarized in paragraphs 263 and 264.

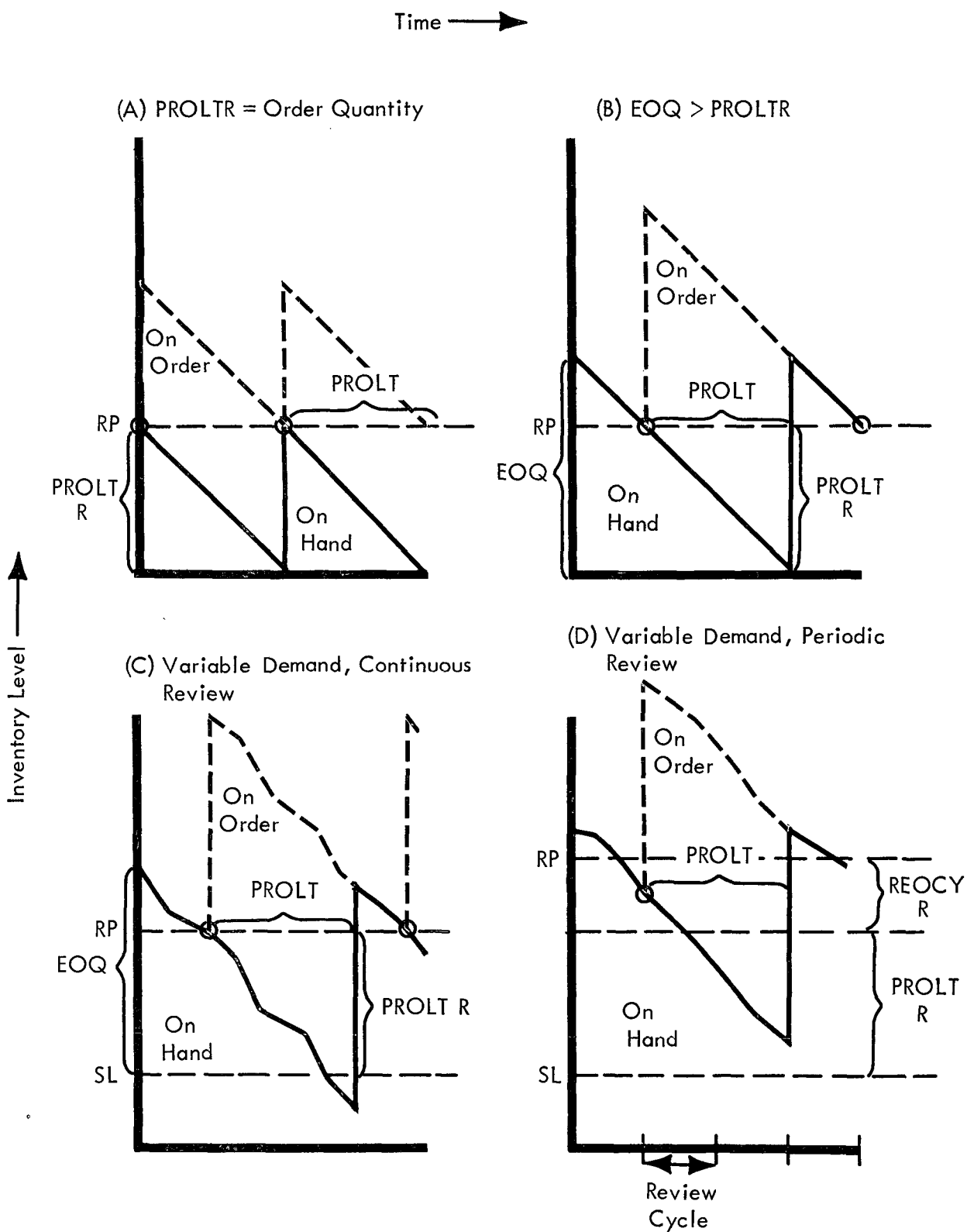


Figure 56. Reorder point relationships.

Section II. A HYPOTHETICAL STOCKED ITEM

257. Introduction

a. The characteristics of inventory models can best be demonstrated with illustrative examples. For this purpose, the individual characteristics of a hypothetical stocked item are listed in this section and some representative demand data are generated.

b. As will be apparent in the next paragraph, the characteristics of the hypothetical item were selected to provide a realistic situation, but one that was not unnecessarily complicated. For example, a procurement lead time was selected that exceeds both the economic order quantity and review cycle to demonstrate consideration of both on hand and on order assets. On the other hand, a nonrepairable item was selected to avoid the problem of reversion rates and the decision to procure or rebuild.

c. While it would be possible to highlight the advantages of each inventory model by using different stocked items with tailored demand patterns, it is believed that the use of a single group of data will simplify comparisons

without unduly biasing the model's relative performance.

258. Item Characteristics

a. Unit Price, $U = \$250$ (no quantity discounts)

b. Forecasted Annual Demand, $Y = 120$ units

c. Forecasted Annual Dollar Demand — $\$250 \times 120 = \$30,000$

d. Control Classification = *HDV*

e. Review Cycle = 3 months

f. Procurement Lead Time, $PROLT = 7$ months

g. Average Monthly Demand, $\bar{y} = 10$ units

h. Standard Deviation of Monthly Demand, $\sigma = 5$ units

y

i. Cost to Order, $C = \$200/\text{order}$

j. Cost to Hold, $H = 20$ percent per year

k. Type = Nonrepairable

259. Generation of Demand Data

a. Based upon the monthly average demand (\bar{y}) of 10 units, the standard duration (σ_y)

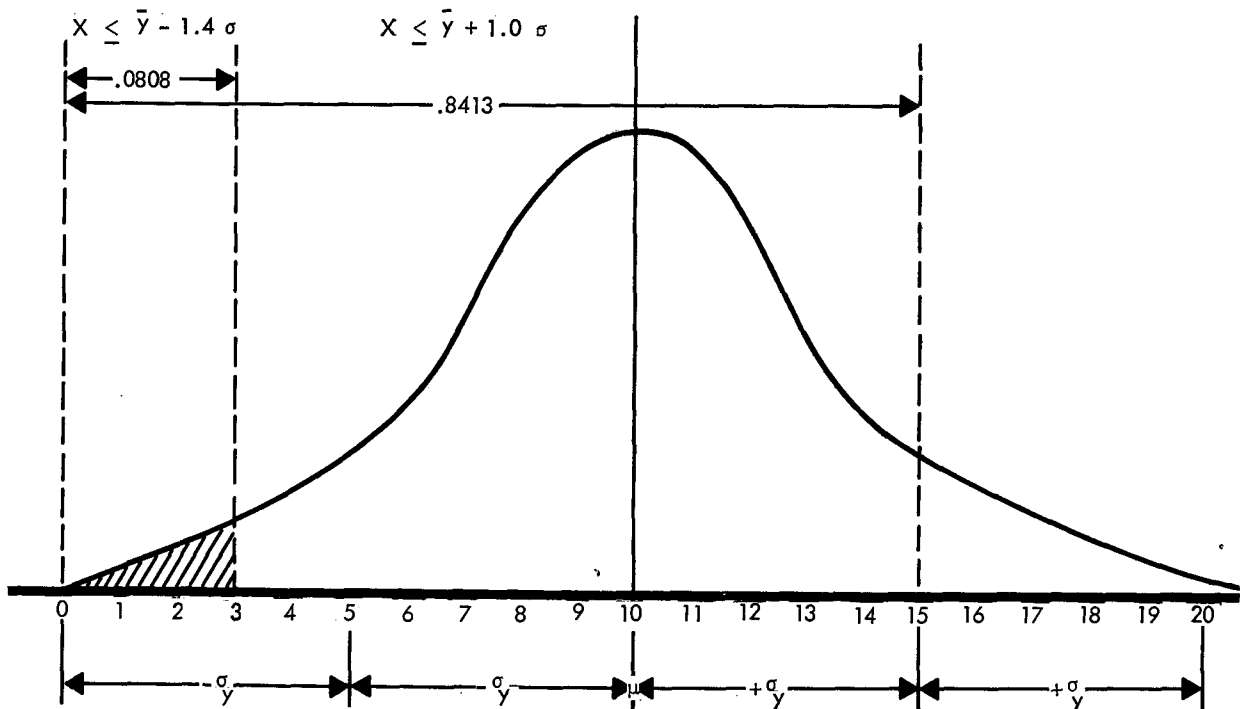


Figure 57. Demand distribution of example stocked item.

Table 25. Random Numbers Used for the Generation of Demand Data

Random Numbers Used for Generation of Demand

<u>Monthly Demand (Units)</u>	<u>Probability of This Demand or Less</u>	<u>Assigned Random Numbers</u>
0	.0228	00-01
1	.0359	02-03
2	.0548	04-05
3	.0808 *	06-08
4	.1151	09-11
5	.1587	12-16
6	.2119	17-21
7	.2743	22-27
8	.3446	28-34
9	.4207	35-42
10	.5000	43-50
11	.5793	51-58
12	.6554	59-66
13	.7257	67-73
14	.7881	74-79
15	.8413 *	80-84
16	.8849	85-88
17	.9192	89-92
18	.9452	93-95
19	.9641	96
20	.9772	97
21	.9861	98
22	.9918	99

* Examples indicated in Figure 57

of 5 units, and an assumption that the demand for this item would resemble a normal distribution pattern, a table was established to permit the use of random numbers for the generation of demand data. The assignment of random numbers to monthly demands was derived from the areas under the normal curve as shown in figure 57. The results are shown in table 25.

b. Twenty-four random numbers were then taken from an appropriate table and used to

generate two years of monthly demands. In the table 26, these random numbers are listed in the order drawn, and the demand each represented is indicated.

c. The characteristics of these generated demand data are shown in figure 58. The frequency of occurrence of demands of various magnitudes is illustrated by the bar chart. It will be observed that the generated pattern only roughly approximates the shape of the normal curve. This is not surprising,

Table 26. Random Numbers Used to Generate 2 Yrs of Monthly Demands

Random Numbers Used to Generate 2 Yrs of Monthly Demands

<u>Month</u>	<u>Random Number</u>	<u>Generated Monthly Demand (Units)</u>
1	56	11
2	28	8
3	41	9
4	72	13
5	49	10
6	74	14
7	87	16
8	84	15
9	90	17
10	98	21
11	83	15
12	22	7
13	25	7
14	81	15
15	10	4
16	42	10
17	48	10
18	29	8
19	06	3
20	88	16
21	61	12
22	18	6
23	04	2
24	42	9
Total Demand		258
Average Monthly Demand		10.7

however, with only 24 pieces of data. The line chart shows how demand varied across time with a great deal of monthly variation about an overall average (10.7) that closely approached the forecasted average (10.0).

d. These demand data will be used in the examples given in paragraphs 261 and 262.

260. Qualification

Before proceeding to the development of the selected inventory models and examples of their

response to the generated demand data, it should be pointed out that the appropriateness of a model cannot be judged accurately on the basis of as few as 24 data points. These data are sufficient to illustrate certain general features of the models but not evaluate their overall usefulness. On the other hand, the technique the example illustrates—that of simulating demand data and using it to exercise selected models—is an important inventory control research method. In a valid research

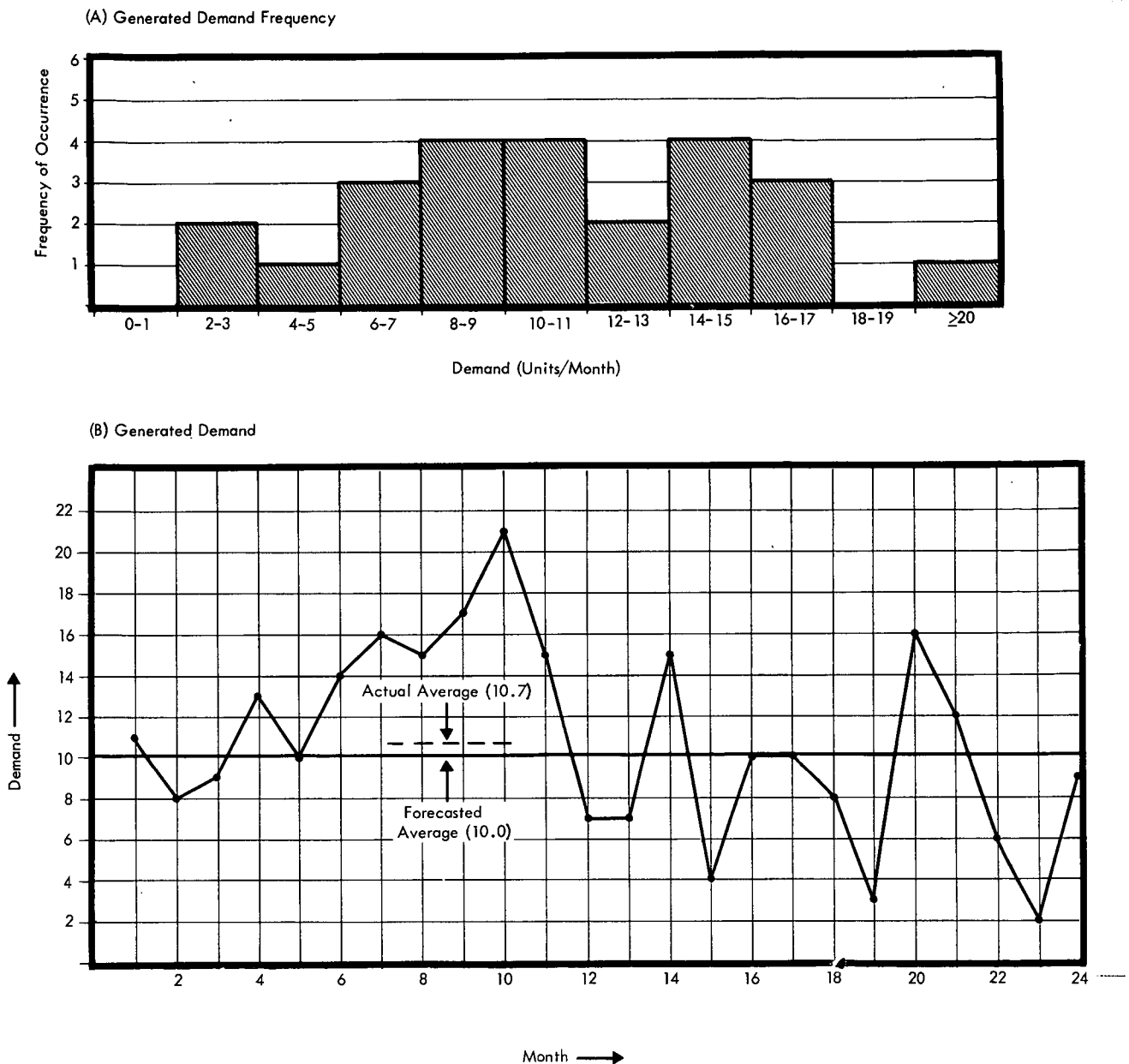


Figure 58. Characteristics of generated demand data.

application, many years of data would be generated for a wide cross section of representative stocked items. Therefore, the examples

contained in this chapter illustrate the technique but not the required depth of analysis.

Section III. DEVELOPMENT OF MODELS AND THEIR RESPONSE TO GENERATED DEMAND DATA

261. Simple Replenishment Model

a. The simple replenishment model is sometimes called a maximum liability model because assets on hand and on order can never exceed a predetermined maximum. Stock is ordered at cyclical review intervals, and the order quantity is always that demanded during the most current review cycle. An order is always placed unless demand during a review cycle has been zero.

b. No order quantity is calculated for a replenishment model. The average order quantity, however, is imputed by the selection of the review cycle, for, as was previously stated, the quantity ordered will be that demanded during the review cycle. Because the review cycle for our hypothetical stocked item is 3 months, the average order for this model should be about 30 units.

c. In a simple replenishment model there is just one number to be determined, *RO* (the maximum asset level). Since on hand or on order assets must be provided for both the review cycle period (*P*) and the procurement lead time, the *RO* is established as:

$$RO = \bar{y}(PROLT + P) + VSL$$

d. Similarly, to be consistent, the variable safety level quantity is:

$$VSL = K\sigma_y\sqrt{PROLT + P}$$

The letter *K* in this expression stands for a multiplier that relates the demand variability to a level of protection. For example, if a value of $K = 2$ was used, 97.7 percent protection against stockouts would be provided. Note that *P* is not divided by 2 in either of these expressions, since an order is *placed to a level, not when a level is reached* (which may or may not occur at the instant of an asset review).

e. Then, for the hypothetical stocked item:

$$VSL = (2)(5)\sqrt{7+3} = 32$$

$$RO = 10(7+3) + 32 = 132$$

and the operating rules can be stated as:

- (1) Review asset status at intervals of duration *P*.
- (2) Reorder *RO* less on hand and on order assets on each occasion.

f. The performance of this model for the simulated demand data is shown in figure 59. In this instance, the on hand inventory position is below the safety level quantity about one-third of the time, and stockouts occur twice. Order sizes during the 24-month period varied from a high of 54 units to a low of 21 units, reflecting the large variability in demand during the 3-month review cycles. The upward trend in demand during the fall of year 1 resulted in two large orders; but because of the 7-month PROLT, stockouts occurred before the orders were received.

g. During the 2-year span, eight orders were placed and the average on hand inventory was 38.0 units (including both operating and safety levels). The total variable costs for the simple replenishment model over the 2-year period may then be calculated as follows:

$$TVC = (\$200)(8) + (38.0)(.17)(\$250)$$

$$TVC = \$1600 + \$1615 = \$3215$$

Note that no costs have been charged for the two stockouts.

262. Optimal Replenishment Model

a. The mathematical development of the decision rules for the optimal replenishment model is considerably more complex than that for simple *Q* and replenishment models because the basic equations for the optimal replenishment model normally include a consideration of variable factors (shortage costs and interactions between protective stock levels and order quantities).

b. The M.I.T. model used at several NICP's is a variation of an optimal replenishment model. The reorder cycle level (*REOCYL*) quantity, which is derived as part of the application of the model, is synonymous with the minimum order quantity of the basic (*S,s*) model. Since the features and assumptions of

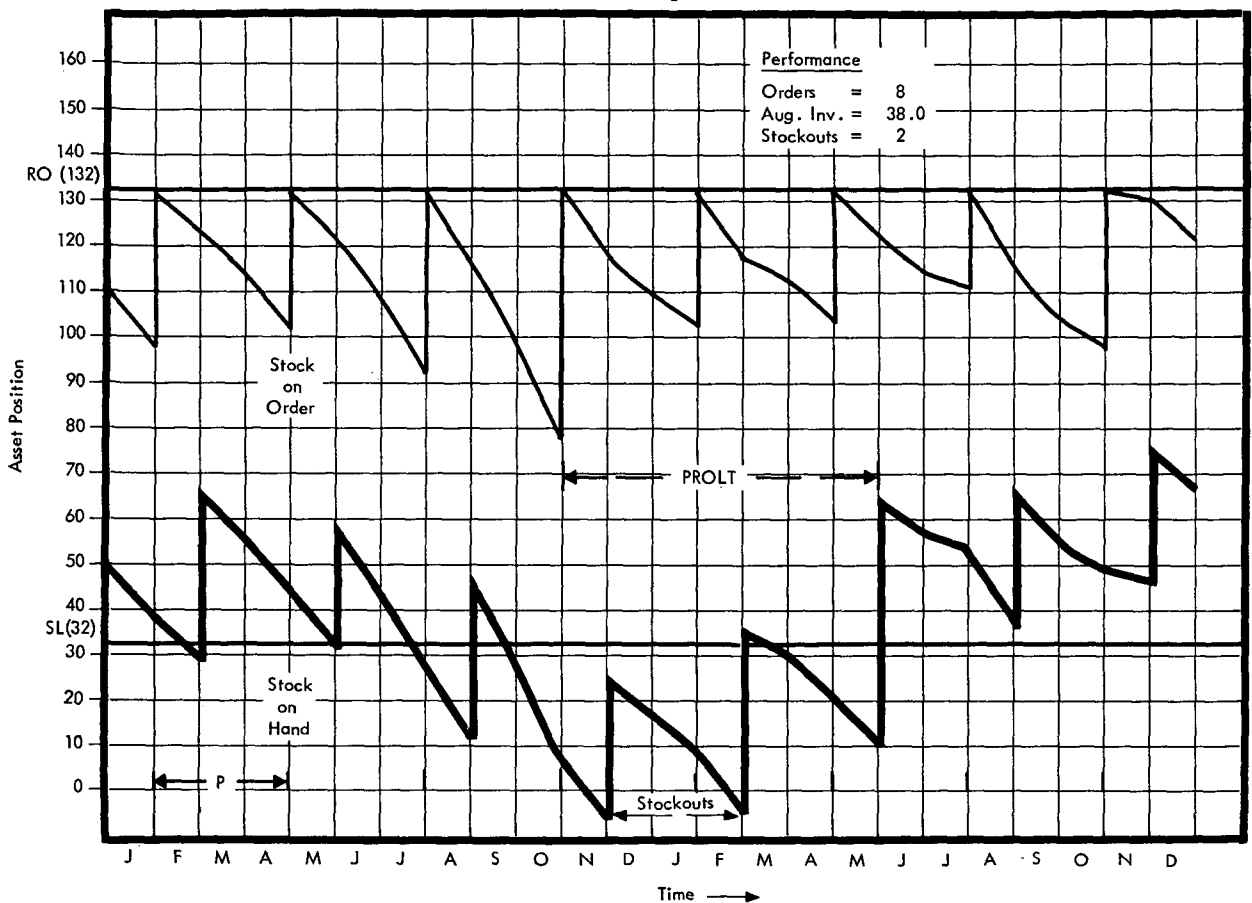


Figure 59. Replenishment model (RO).

this model were reviewed in chapter 13, they will not be repeated here. However, the parameters of our example optimal replenishment model will be determined on the basis of the M.I.T. calculation, as follows:

VMR for $U = \$250$ and $Y = 120$ is 9.8

$$Z = \frac{200}{.17 \times 250 \times 7/12 \times 9.8} = 0.824$$

$$a_{.99} = 1.72 \quad a_{.95} = 0.92$$

$$VLT = \sqrt{120 \times 7/12 \times 9.8} = \sqrt{686} = 26.2$$

$$SL_{.99} = 1.72 \times 26.2 = 45$$

$$SL_{.95} = 0.92 \times 26.2 = 24$$

$$SL_{.97.7} = (\text{by interpolation}) = 35$$

$$PLTR = 120 \times 7/12 = 70$$

$$b_{.99} = 1.73 \quad b_{.95} = 1.88$$

$$PCL_{.99} = 1.73 \times 26.2 = 45$$

$$PCL_{.95} = 1.88 \times 26.2 = 49$$

$$PCL_{.97.7} = (\text{by interpolation}) = 47$$

$$REOPT = SL + PLTR = 35 + 70 = 105$$

$$RO = REOPT + PCL = 105 + 47 = 152$$

Note. Readers not familiar with the detailed computations of the M.I.T. procedure should not attempt to follow the above calculations.

The three quantities determined for the optimal replenishment model through these calculations are a safety level of 35 units, a reorder point of 105 units (on hand or on order), and an order quantity of 47 units. The RO is, therefore, $105 + 47 = 152$ units.

c. An optimal replenishment model that operates on the basis of continuous review is described once the RO and REOPT quantity levels have been determined. The operating rules are—

- (1) Review asset status continuously.

Section IV. SUMMARY

263. Advantages and Disadvantages of Inventory Models

a. Four models were discussed in paragraphs 254 through 256 and two of these were demonstrated in paragraphs 261 and 262. However, since the periodic review Q model is merely a constrained variation of the simple lot size Q model, it will not be discussed further in this section. The three remaining models, simple Q, simple replenishment, and optimal replenishment, each have special features that must be evaluated whenever a possible inventory application is being considered.

b. The simple replenishment model is the easiest to formulate and has a quick response to increases in demand. On the other hand, while the RO quantity represents a maximum level of on hand and on order assets, it is possible to reach this level in terms of stock in inventory whenever demand is zero for a period equal to the procurement lead time. For this reason, the holding costs for this model tend to be higher than those for other models during periods of slack demand. Further, the operating rule of reordering to the RO at each review can often result in the procurement of uneconomically small lot sizes.

c. The simple Q model is also easily formulated but responds less quickly to increasing than does the replenishment model. Stockouts frequently result during periods of increasing demand when this model is used unless new safety levels and EOQ's are calculated on the basis of a new average demand rate. Conversely, the reorder point feature of the Q model prevents high inventories in periods of low demand.

d. The optimal replenishment model has certain advantages of both simple Q and replenishment models and has been shown in technical literature to have the lowest total operating cost of all three models in a variety of applications and over a wide range of operating conditions. Its main disadvantage is the difficulty of calculating the RO and REOPT quantities for even the simplest distribution functions. To overcome the computational

problem, common practice is to develop a model that fits the characteristics of a "representative" sample of line items and then to apply these parameters to an entire inventory system. This approach is fine if the cross section of items in inventory has similar demand variances and distributions. When applied inappropriately, however, the optimal replenishment model results in suboptimum performance.

e. The advantage of continuous status review over periodic, for any model, is that it eliminates the need for one inventory stratification (average or one-half the average demand over the review period) and thereby reduces the average investment in on hand stocks. Conversely, perpetual inventory records are more costly to maintain than ones updated on a periodic basis since they require more frequent data inputs, central processing, and output reporting. It is thus apparent that a trade-off exists between operating and investment costs that should be considered when choosing between a continuous and periodic review model. It should also be recognized, however, that these two policies approach each other as a limit when, on the one hand, the review period is made shorter and shorter and, on the other hand, stock status lag times cannot be economically eliminated.

264. Special Cases

a. Inventory models are generally developed by operations research analysts and then applied by supply management personnel. For this reason, while it is not necessary that the operators of the system understand the mathematical expressions and procedures used in a model's design, they should know in general terms how a model will respond to unusual situations. If, for example, an EOQ is determined that is less than the review cycle quantity, the analyst should recognize the need for instituting a continuous check on asset balance or for scheduling a second procurement prior to the next review time. Similarly, if a model is designed on the basis of a periodic review and an ADPS improvement (e.g., random access makes it possible to check

asset status continuously, the analyst should realize that RO or REOPT quantities may be safely reduced.

b. It would be impossible in a single manual to discuss all inventory models or the special situations that would render them invalid. Further, as has been mentioned often in other chapters, it is unlikely that even the most sophisticated of the present models approach a truly optimum representation of the overall cost and performance parameters of the Army

logistics system. Personnel in supply management activities should therefore continue to become as familiar as possible with the unique characteristics of the stocked items they control and should use standardized mechanical procedures when they are appropriate, but they should always question unusual "answers" and apply personal judgement. In the review of the supply control study unusual "answers" can best be spotted by comparing the current to previous studies.

CHAPTER 17

MULTI-ECHELON CONSIDERATIONS

Section I. GENERAL

265. Structure

a. A multi-echelon supply system is one that has a number of levels or tiers of inventory stockage and control points, each of which issues supplies to lower level customers and replenishes its own stocks by requisitioning or procuring from a higher level. The Army supply system is a multi-echelon system. Figure 61 illustrates the multi-level nature of the Army system in a simplified structural diagram.

b. While only five levels are shown in figure 61, in actual practice there may be as few as two or as many as seven or eight stockage levels between the initial receipt of a manufactured item into the supply system and its ultimate use by a consumer in the field. For example, oversea operations normally introduce at least one or more level into the picture and in many cases, particularly when the problem of initial provisioning is being studied, the manufacturer may also be properly treated

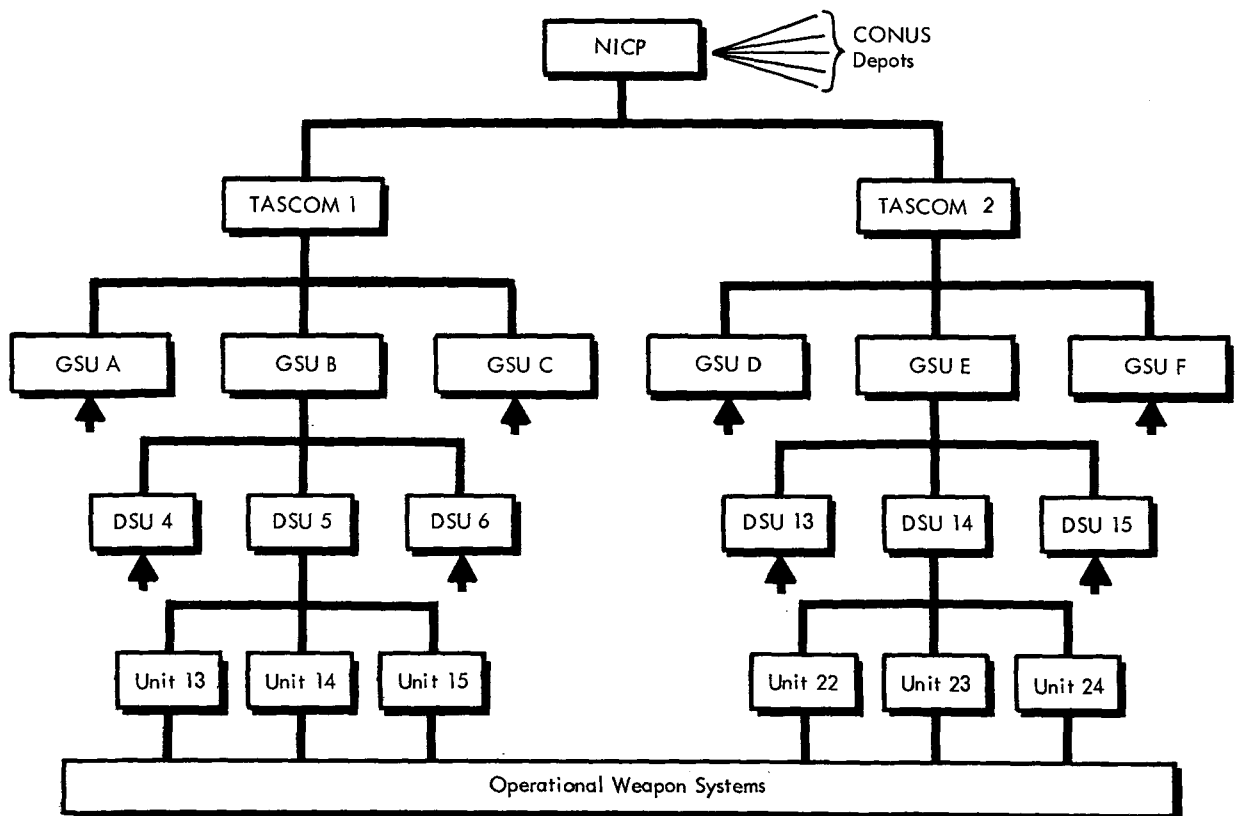


Figure 61. Structure of the multi-echelon supply system.

as a supply system level. On the other hand, some high unit value repairable items (i.e., aircraft engines) are stocked at only two levels.

266. System Considerations

a. A multi-echelon system can be adequately studied only through the systems approach. Decision rules at each level can be shown to influence stockage levels and replenishment actions at all other levels. For this reason, what may appear to be a least cost solution to a problem existing in a specific segment of the supply system may instead increase the overall cost of the system. This fact may only be revealed by studying the system as a whole.

b. Unfortunately, analyses of something as large and complex as the Army supply system are extremely complicated. Little mathematical modeling of multi-echelon systems has been done because not all of the dynamic elements of the system have been identified or measured sufficiently to permit their expression in abstract equations. However, an increased understanding of multi-echelon systems is being gained through current research, primarily by the application of simulation techniques using large-scale computers.

c. The first hurdle to overcome before a system optimizing model can be developed is

that of establishing measures of performance for the system as a whole. This is not a simple task. For one thing, performance includes at least two factors—service and cost. When or where should service considerations govern to the exclusion of costs? How much is a 5 percent increase in service performance worth? Many other similar questions could be asked about the interaction of service and cost in a multi-echelon system. Of more important interest, however, is the question of where performance should be measured. For example, the NICP may be most concerned about the time out-of-stock at the wholesale level, the distribution depot with the percent of initial fill, and the field commander with equipment down-time. Which of these indexes, others, or of combinations of factors constitutes a valid and meaningful measure of the system's performance?

d. It will not be possible to provide complete answers to the above and earlier questions in this chapter. More research must be accomplished. However, in the following sections several characteristics of multi-echelon systems will be illustrated, the somewhat surprising conclusions drawn from recent research projects will be noted, and the impact of further research on the operation of the supply system appraised.

Section II. MULTI-ECHELON EFFECTS ON PIPELINE

267. Definition

The general nature and function of the supply pipeline has been discussed and illustrated in FM 38-2-1. In brief, it is the physical system of supply from the manufacturer to the ultimate consumer in the field. Often pictured as a series of surge tanks or pumps joined by connecting pipes of varying lengths, the materiel pipeline quantitatively includes both stocks in storage and in transit between inventory points.

268. Factors Affecting Pipeline Quantities

a. *Supply System Factors.* Many supply system factors determine the total quantity of materials which will be in the system pipeline at any one point in time. Among these factors are—

- (1) Frequency of demand
- (2) Number of levels
- (3) Transit time
- (4) Variations in demand
- (5) Maintenance practices

The effect of each of these factors is discussed below.

b. *Frequency of Demand.* Basic stock control policies, as prescribed in AR 711-16, affect pipeline quantities by stipulating that stockage lists will be determined on the basis of the frequency with which an item is requisitioned except for mission essential, standby or insurance type items. If an item is demanded less often than the minimum frequency established, it will not be stocked and surge inventory and in-transit quantities will therefore be zero. On the other hand, if an item is req-

quisitioned regularly at all levels of command, it will be distributed throughout the pipeline. Also, standards are based on the frequency of demands rather than on the number of units demanded, requisitioning practice can have a measurable effect on whether or not an item will qualify for stockage. For example, if the criterion is three demands a year and four widely dispersed companies each placed one requisition for two units on a DSU, the item would qualify for stockage and total demand would have been 8 units. In another case, a battalion might requisition 10 units and, if this was the only demand placed on the DSU during the course of a year, the item would not qualify for stockage.

c. Number of Levels. The more levels there are in the supply system the greater will be the average quantity of stock in the pipeline. Each level will have some on-hand inventory of items which qualify for its stockage list. On the average, this inventory will be composed of a safety level quantity (normally 15 days' usage at the retail level) and one-half the operating level ($30/2 =$ another 15 days' supply at the retail level). Low annual dollar demand items which are requisitioned on an EOQ basis will have even larger inventories when expressed in days of average usage. The number of levels in the system not only affect pipeline quantities directly in terms of inventoried surge stocks, but also indirectly because the amount of stock that is in transit will be increased because of the additional handling and delays inherently associated with each level.

d. Transit Times. Pipeline quantities are a direct function of shipping times. For example, if an item is used at the rate of one a day, 30 units would be in transit, on the average, if transit is 30 days. Conversely, only 4 units would be in transit if the delivery time was reduced to 4 days by the use of airlift or another means of expediting shipment. However, it should be recognized that transit time quantities in the pipeline are not affected in the long run by the use of partial shipments. If the length (delivery time) of the pipeline remains fixed at 30 days and usage remains constant at 2 units per day, there will be, on the average, 60 units of this item in transit re-

gardless of whether the item is ordered in lots of 10, 30, 60 or more units. If this fact is not intuitively obvious, reference to illustrations contained in FM 38-2-1 should clarify this point.

e. Variations in Demand. Stockage, requisitioning, and requirements objectives are all affected by the amount of variability in demand. These supply control guidelines are used to establish the quantities of stock-on-order and on-hand at the several inventory points in the supply system. Fixed safety levels, operating levels, and order and shipping time or procurement lead time levels are all a function of forecasted average demand rates, which, in turn, vary in size and accuracy with the variations in historical demand and the type of smoothing technique utilized. Further, when variable safety levels are used, the safety level quantity is a direct multiple of the variability as measured by the standard deviation of demand.

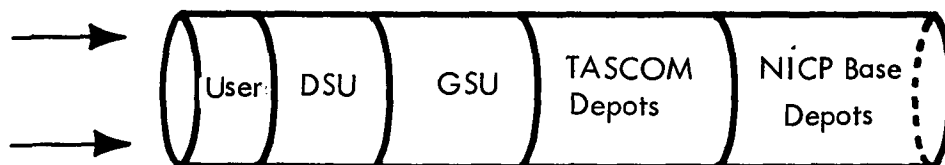
f. Maintenance Practices. It is apparent that the quantity of repairable materiel in the supply pipeline will be affected by maintenance policies relative to the level at which maintenance activities are performed and how extensive they will be. Each maintenance point will have some average accumulation and in-process inventory level depending on economic lot sizes and variability in demand. The total maintenance float will be greater for a system with more layers if all other factors are held constant. The transit time observations made earlier are equally applicable to repairable items, except in this case it is a two-way street—unserviceable items being returned up the stream for maintenance and repaired or rebuilt items returning downstream for stockage or use. Further, the number of items in inventory, but not necessarily the dollar value of the inventory, can be reduced through the use of modules or kits in lieu of individual repair parts.

269. Dynamic Characteristics of the Pipeline

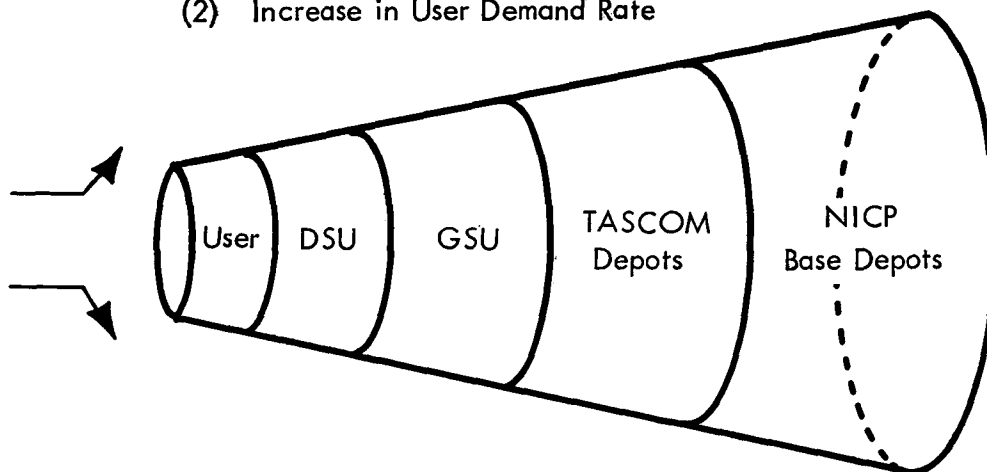
a. It is evident from the foregoing discussion that pipeline quantities may be reduced by changing the organization and operation of the system. By centralizing inventory stockage and control, the numbers of layers may be reduced,

and commensurately, the amount of materiel in the pipeline. Similarly, by improving order processing and handling times, and through the use of improved means of transportation, even further reductions in pipeline quantities may be achieved. A quantitative measure of the effect of such changes on worldwide inventories

is superficially quite straightforward and savings in holding costs may be easily contrasted with the increased costs of data processing or transportation. Unfortunately, such an analysis is clear cut only when the system can be treated as static with constant demand rates. Even in this simple case, universally accept-



(2) Increase in User Demand Rate



(3) Decrease in User Demand Rate

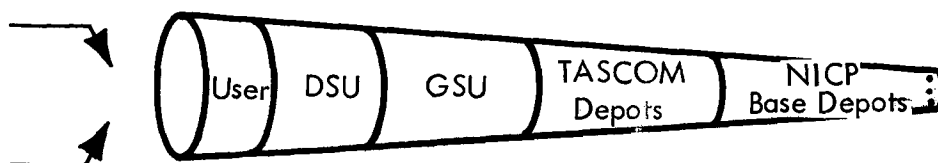


Figure 62. Effect of a change in demand rate on pipeline.

able measures of cost and service performance are difficult to determine.

b. The Army supply system is in fact extremely dynamic. Not only are new policies and procedures being regularly implemented which change historic supply and demand patterns (e.g., Command Stock Fund), but new weapon systems are being introduced, equipment densities changed, and troop deployments shifted to reflect a current cold war emphasis. All of these latter factors have an influence on pipeline quantities and conspire to make an analysis of the systems' response to change extremely difficult to measure.

c. The effect of a change in demand on the various levels of a multi-echelon supply system can be depicted graphically as shown in figure 62.

The upper diagram illustrates a five-echelon pipeline at an equilibrium condition when demand is constant and has remained so for some time. Under these conditions, the moving average of demand may cover different time intervals for each echelon and the operating level times, safety level times, and order ship times may differ. However, since demand is unchanging, the demand by each echelon is identical to the demand on that echelon. For example, a total demand of 100 by all consumers yields a total demand of 100 on the top echelon.

d. However, when demand rates change, the pipeline also changes. The center diagram of figure 62 illustrates the theoretical effect of an increase in demand rate and the lower diagram of a decrease in demand. Note that the demand by each echelon is greater or less than the de-

1 Month	2 Demand by User	3 Moving Avg at DSU (6 mos)	4 Auth. Levels (2 mos)	5 Bal After Filling Rqn	6 Demand on GSU	7 Moving Avg at Army Depot (10 mos)	8 Auth. Levels (4 mos)	9 Bal After Filling Rqn	10 Order on TASCOM Depot	11 Moving Avg. at TASCOM Depot (quarterly)
Start	60	60	120	60	60	60	240	180	60	60
1	120	70	140	0	140	68	272	100	172	
2	120	80	160	20	140	76	304	132	172	
3	120	90	180	40	140	84	336	164	172	71.5
4	120	100	200	60	140	92	368	196	172	
5	120	110	220	80	140	100	400	228	172	
6	120	120	240	100	140	108	432	260	172	88.0
7	120	120	240	120	120	114	456	312	144	
8				120	120	120	480	336	144	
9						126	504	360	144	98.5
10						132	528	384	144	
11						130	520	408	112	
12						128	512	400	112	106.3
13						126	504	392	112	
14						124	496	384	112	
15						122	488	376	112	112.9
16						120	480	368	112	
17						120	480	360	120	
18								360	120	120.0
21										127.5
24										135.0
27										128.5
30										122.0
33										119.0
36										118.6
39										119.6
42										120.0

Figure 63. Effect of a change in demand on a three echelon supply system.

mand placed on that echelon. This magnification or reduction is due to the fact that a change in demand rate affects not only operating levels but also safety levels, and order and ship time quantities. Depending upon the number of levels and operating rules in use, a small change in demand at the consumer level could be so increased by the time that it reached the NICP that it might result in an emergency procurement or, conversely, a disposal action.

270. Duration of Pipeline Effects

a. A change in demand not only affects pipeline quantities as a result of the upward or downward amplification illustrated by figure 62, but it also affects the pipeline quantity through time. If a demand increases to a new point and then remains constant, the pipeline may not settle down to a new equilibrium condition for several years. This characteristic of the pipeline is a reflection of demand smoothing techniques. The rate of system response to

change will vary depending on the smoothing technique in use (e.g., moving average, least squares, single or double exponential). This fact can best be illustrated with the simplest and most commonly used smoothing technique, that of moving averages.

b. The chart below shows the time required to adjust average demands to a new demand of 120 from an old rate of 60 when a 6-month moving average is used. (Assume that in each of the previous 5 months there was a demand of 60.)

Response of Moving Average			Moving Average
		Month	
Starting Position	6	60	60
	7	120	70
	8	120	80
	9	120	90
	10	120	100
	11	120	110
	12	120	120

In this case, because a 6-month moving average was used, it takes 6 months for a new de-

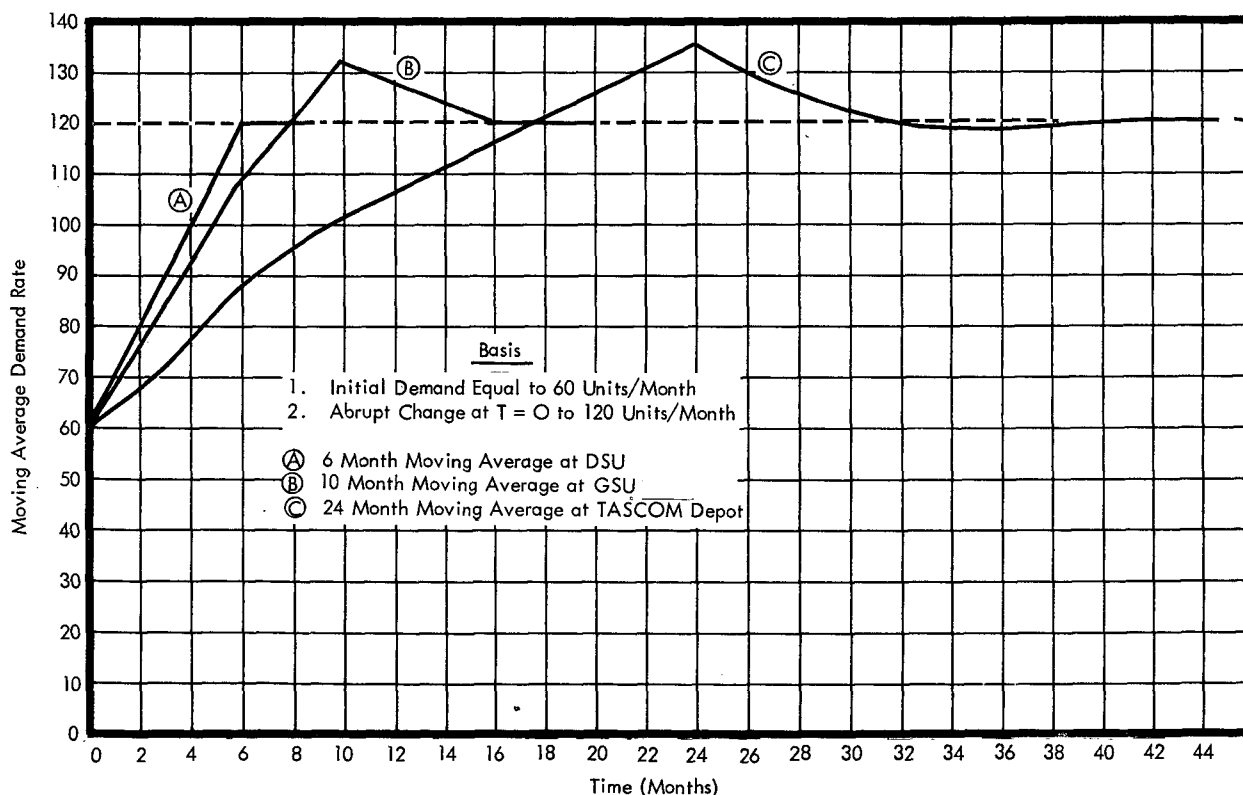


Figure 64. Multi-echelon moving average response to abrupt change in user demand rate.

mand rate to be correctly reflected in averaged demands, and therefore, in operating levels, safety levels, and the like.

c. If in the above example the next higher echelon uses a 10-month moving average, it would not correctly reflect the new demand rate until 16 months had elapsed. Similarly, if the next (still higher) echelon was using a 24-month base period, its moving average would not have dampened down to an accurate portrayal of the demand of 120 units per month until 40 months (6 + 10 + 24) after

the change in rate had occurred. These effects are tabulated in figure 63 and are shown graphically in figure 64. Notice also in figure 63 that the order of 120 on the DSU in month 1 was amplified to an order for 140 on the Army Depot and to an order for 172 on the Base Depot.

d. In brief, changes in demand rate affect the materiel pipeline in two ways—first, the levels are changes; and second, the change occurs over a period of time equal to the sum of the effective smoothing periods.

Section III. PERFORMANCE OF MULTI-ECHELON SYSTEMS

271. Parameters

a. Measurement of the performance of a logistics system normally involved two parameters—cost and service. In chapter 12 major emphasis was directed towards the performance of the wholesale inventory system, the top level of the Army's multi-echelon supply system. How should performance of the system as a whole be measured in terms of cost and service?

b. The cost parameter is simply defined. The cost of a multi-level system is made up of *all* of the variable costs in each of its levels. These would include the cost of the materiels (i.e., quantity discount considerations), NICP costs of ordering and holding, requisitioning, shipping and receiving costs at all levels, all transportation costs and the cost of holding inventory at each of the numerous stockage points. In addition, the cost of reacting to a shortage condition should be included at levels above the consumer and some estimate should be incorporated of what it costs the user for equipment unavailability because of stockouts. With the exception of the out-of-stock cost, these system costs can be determined in a straight-

forward manner for any given situation. Expressing their interrelationships mathematically for the purpose of analytically deriving a minimum cost solution is difficult but feasible.

c. The service parameter of performance presents a bigger problem. In most cases it is difficult to get more than two people to agree on what constitutes a suitable definition of system service performance and even more difficult to express an acceptable index in a form which is analytically tractable.

272. Indexes of System Service Performance

a. Most analysts of logistics systems will agree that, ultimately, the only service which truly matters is that service to the final consumer of the item or part. Late deliveries or unfilled requisitions at higher levels may be indicative of future problems, but, at any one point in time, the service level of the system is a function of how many end items in the field are required and how many are fully operational.

b. If this approach is taken, system service performance might be measured as:

$$\text{System Service Performance} = 100 \left\{ 1 - \frac{\text{Time that a maximum number, "n," of weapon systems, "s," are out of service due to lack of parts}}{\text{Total time weapon systems are required for service}} \right.$$

$$\frac{\text{Time that a maximum number, "n," of weapon systems, "s," are out of service due to lack of parts}}{\text{Total time weapon systems are required for service}}$$

To illustrate how this index would work, assume that there are twenty weapon systems of type "s" in the hands of users and that a mini-

num of eighteen are required to be in serviceable condition at any given time in order that there be an acceptable level of combat capabil-

ity. The supply system would not be penalized in this case unless more than two systems were down due to lack of parts at the same time. Continuing with the example: if the measure of service was made over an interval of 100 days, and if more than two systems were down for a period of 5 days, the measure of performance would be:

$$\left(1 - \frac{5}{100}\right) 100 = 95\%$$

It is apparent that this measure has a weakness in that it does not measure relative performance when performance is unsatisfactory. That is, the index would not differentiate between three weapon systems being down for 2 days and four weapon systems being down for 2 days. Nonetheless, if the above measure was accepted as a measure of system performance, standards and inventory models up and down the multi-level system would have to be changed to reflect it. For example, demands for stock replenishment would have to be treated differently than demands for direct replacement.

c. Another more sophisticated measure of service performance currently being investigated by an Army logistics research group is titled "strategic unavailability." This measure is defined as the product of the probability of the weapon system being inoperative due to a part failure and the average duration of the inoperative period. In this case, the weapon system can be restored to service by having one or more spare systems available or by replacing the assembly containing the failed part. The assembly, in turn, may either be replaced by a serviceable one from storage or it may be further disassembled for repair, and so on. A level in the weapon system will finally be reached where the failed unit cannot be further disassembled and must be replaced by a spare part from serviceable inventory. This model permits the calculation, once the weapon system "strategic unavailability" requirement is established, of the number of spare units of each type, and the "strategic unavailability" required of each part, in order to attain the weapon system requirement at least cost. Thus, a need to specify arbitrarily the relative essentiality of parts or the allowable customer wait time and necessary repair part inventory

levels is avoided. The present difficulty associated with this model is the number of engineering analyses which must be performed on each weapon system to obtain the necessary input data. Further work is proceeding along the lines of testing the sensitivity of the model to various simplifying assumptions.

273. Simulated Performance of Multi-Echelon Systems

a. The bulk of the analysis of multi-echelon systems, in the Army and elsewhere, has been performed through the use of simulation techniques. As noted in chapter 14, it is possible to simulate on a computer the behavior of systems which are too complex to analyze manually using the more traditional mathematical tools. A multi-echelon system can be programmed into a computer model which contains several interacting supply levels, each with its own realistic decision rules (e.g., based on AR 710-45 at the wholesale level and AR 711-16 at the retail level), and, by using randomly generated demands drawn from a selected demand distribution, the system's response can be tested over a period of several years. The decision rules may then be varied and another run simulated in the computer. Thus, through intelligently selecting modifications in policies and procedures, the simulation model can be made to converge iteratively on a most optimum solution.

b. Simulation studies of the Army's multi-echelon system are being made at the Army Logistics Management Center, Ft. Lee, Va., and by the AMC Inventory Research Field Office at Frankford Arsenal, Philadelphia. Two early Frankford Arsenal studies are described in the following paragraphs for illustrative purposes. It should be borne in mind that the results and conclusions are very preliminary in nature.

c. One model concerned a two-level system and involved, as a supply item, repairable aircraft engines. The problem considered was the optimum distribution of a fixed number of spare engines between "national" stocks and a number of geographically decentralized inventory locations. In this application, the customers were user organizations that needed a serviceable engine to replace one that had

failed or had reached a maximum allowable operating time. The measure of performance adopted was "customer wait time," which the study attempted to minimize. Performance was simulated according to the following rules:

- (1) If a serviceable spare engine is on hand in the customer's geographical area, there is no waiting time.
- (2) If one is not available, the customer waits a varying length of time depending on whether—
 - (a) An unserviceable spare is under repair or available for repair in his geographical area.
 - (b) A serviceable spare is already in transit to his geographical area from the national inventory as a result of a previous replenishment demand.
 - (c) No spare is available in his geographical area but the national in-

ventory has a serviceable spare and can ship it on request.

- (d) The national inventory has neither serviceable nor unserviceable spares on hand but must wait for an unserviceable engine to be turned in before it can begin overhaul.

d. Several assumptions were used to simplify the original design of this model—

- (1) Removal rates in each of ten geographical areas have equal means and Poisson distributions.
- (2) All pipeline times are equal for all areas.
- (3) All areas are of equal military priority.

e. Some of the important results obtained from the simulation of this model are preprogrammed into a computer model which consented graphically in figures 65 and 66. The above figure compares the customer wait, given a fixed number of spares, under a dis-

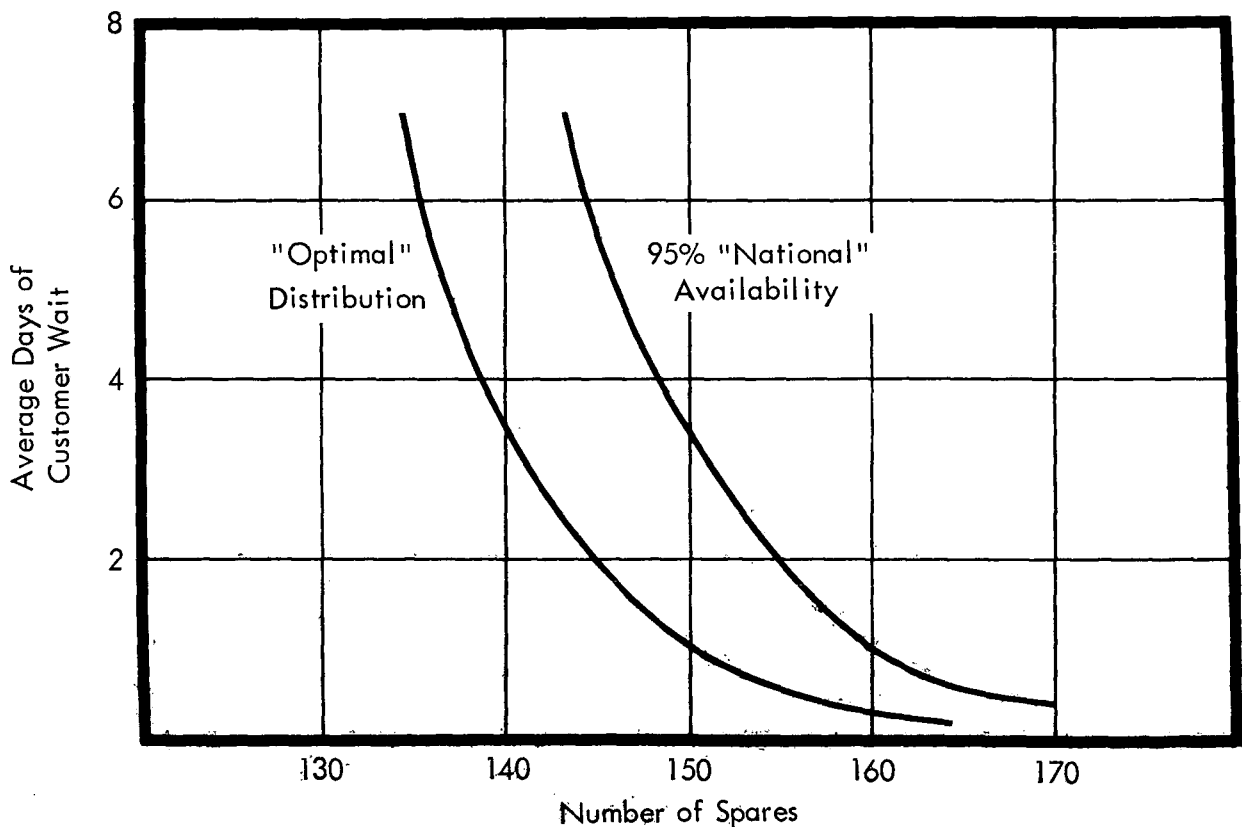


Figure 65. Optimal performance versus 95% availability at national level in a two-level system.

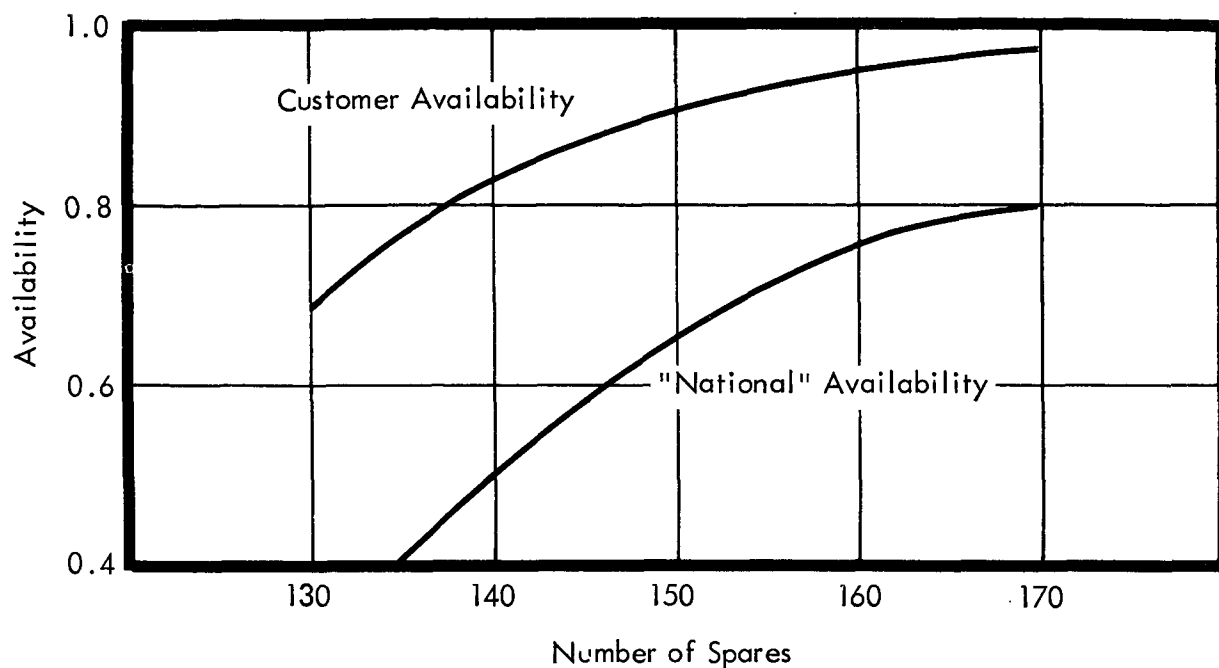


Figure 66. National versus customer availability in a two-level supply system.

Annual Failures	Unit Price	Fraction of Time Out-of-Stock at:				
		National Inventory	Depot	Post	Direct Support	Org. Support
50	\$50.00	.07	.21-.42	.19	.04	.01
		.31	.43-.65	.19	.06	.01
		.53	.60-.82	.13	.06	.01
100	\$ 2.00	.10	.24-.36	.07	.08	.02
		.32	.41-.60	.15	.10	.02
		.42	.50-.66	.18	.15	.06
1,000	\$100.00	.22	.30-.39	.50	.22	.04
		.40	.46-.58	.52	.22	.04
		.62	.66-.74	.51	.21	.04
1,500	\$200.00	.03	.05-.12	.03	.06	.01
		.14	.21-.27	.04	.06	.01
		.38	.45-.51	.06	.07	.01
3,000	\$600.00	.01	.01-.02	.04	.03	.01
		.05	.10-.22	.07	.03	.01
		.27	.35-.50	.05	.03	.01

* Frankford Arsenal Study, 1964

Figure 67. Simulated performance of a multi-level inventory system.

tribution plan designed to yield 95 percent "national" availability and under an "optimal" distribution plan which minimizes customer wait but lowers national availability.

In figure 66 the relationship between national availability and customer availability under the "optimal" distribution plan is shown. The conclusion to be drawn from a detailed analysis of this data is that used performance can be improved by locating a larger percentage of a limited number of spare parts at the user level instead of at the national level.

f. The second model was also concerned with the relationship which exists between the "top" and the "bottom" of a multi-echelon supply system. The system simulated in this case was similar in organizational structure to that illustrated in figure 61 and contained—

- (1) Six depots
- (2) 26 posts
- (3) 84 direct support units
- (4) 252 organizational units
- (5) 756 units of a particular equipment distributed among the 252 organizational units.

g. The following rules or characteristics were incorporated into this more complex model:

- (1) Failures were assumed to follow a stationary Poisson process.

- (2) All organizational units were permitted to stock the part if they met the criteria of AR 711-16.
- (3) Reorder points and order quantities were based on AR 711-16.
- (4) Lag times for requisitioning and shipping were built into the model. Expediting actions were allowed when the stocking organization was out-of-stock.
- (5) The national inventory manager controlled inventories of the depots on a basis of AR 710-45 using the M.I.T. system.
- (6) A post's demand could be satisfied from any of the six depots.

h. Early results from the simulation of this multi-echelon model are tabulated in figure 67. Note the relative insensitivity of the user's condition to changes in levels of operation at the "top" of the system. The conclusion may be drawn from these preliminary computer runs that operating rules at the lower levels have a great deal more effect on the user than those at or near the national level. As mentioned earlier, demand variations are magnified up the multi-echelon system and, based on present inventory models, dictate a requirement for larger safety levels at ICP's and NICP's. This study, and others conducted in industry, suggest that present practices should be seriously reviewed.

Section IV. SUMMARY

274. Suboptimization

a. It is apparent that the operating rules in effect at the various levels of the Army logistics system may result in good performance when considered separately but are suboptimum in terms of the performance of the total system. The degree to which they depart from a true optimum point (cost and service) cannot be accurately determined at this time.

b. Acknowledging the validity of the above conclusion, it is nonetheless evident that the costs and performance of the logistics system have been improved by the implementation of such policies as those contained in AR 710-45 and AR 711-16. That is, while the techniques and procedures presently in use do not con-

stitute an optimum control methodology, they represent an advance in the right direction when contrasted with former methods of supply control.

275. Further Research

a. It follows, therefore, that further research into the nature of the Army supply system should be conducted. The multi-echelon effects of the system represent a research area of significant importance and offer great opportunities for improvement. In this regard, the technique of computer simulation holds the highest promise of yielding meaningful answers at a reasonable cost in the near-term future.

b. Suggested additional readings are listed in the appendix.

APPENDIX

SUGGESTED ADDITIONAL READINGS

Forecasting

Brown, R. G., *Statistical Forecasting for Inventory Control*, McGraw Hill, Inc., 1959.

Brown, R. G., *Smoothing, Forecasting, and Predicting of Discrete Time Series*, Prentice-Hall, Inc., 1963.

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Hanssman, Fred, *Operations Research in Production and Inventory Control*, John Wiley and Sons, Inc., 1962.

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Duncan, A. J., *Quality Control and Industrial Statistics*, Richard D. Irwin, Inc., 1955.

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USAR: None.

For explanation of abbreviations used see AR 320-50.

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